UNIVERSITY OF CALIFORNIA, MERCED

# Dissertation: Examining and investigating home modifications and smart home technologies to reduce fall injury among older adults.

by

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Kwan K., Wiebe D., Cerda M., Goldman-Mellor S. Repeat assault injury among adolescents utilizing emergency care: A statewide longitudinal study. *Journal of Emergency Medicine*. 2019

Kwan K., Boyajian J., Goldman-Mellor S. Longitudinal analysis of emergency department utilization for repeat assault among assaulted adolescents. *Poster Presentation.* Society of Epidemiological research annual conference. June 20th, 2018

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**Abstract**

Nearly one in six U.S. residents are over the age of 65. The proportion of older adults in the U.S. is anticipated to grow to 22.1% of the total population by 2050. The cost of treating age related conditions and injuries is expensive, government programs including Medicaid paid over $550 Billion in 2017, and makes up between 14-16% of the federal budget each year. With the high cost of treating age related conditions and injuries, and the proportion of older adults continuing to increase every year, it is imperative that researchers and government entities find and invest in preventative measures in order to reduce injury and related healthcare costs.

Among the many age-related injuries older adults suffer, falls are arguably the most important to address. It is estimated that one in three older adults has a fall every year. In 2016, falls were the seventh leading cause of death among older adults. Approximately one third of all fallers require medical attention after experiencing a fall. Over 800,000 older adults are hospitalized each year due to fall related injuries. Injuries sustained as a result of a serious fall include various fractures, traumatic brain injuries, and other cuts and bruises.

Home modifications, and more recently smart home technologies, can help increase the safety of older adults living in the community. With older adults wanting to “age in place”, installing these modifications and technologies before an accident happens may lower rates of injury. Today, dozens of companies sell various smart home devices for the consumer market. Bud despite the high demand for these technologies by the American consumer, the ability of these devices to keep older adults safe, and how older adults value these technologies, remains uncertain.

These home technologies may be particularly beneficial to older adults living in rural areas due to the increased isolation and limited access to healthcare resources. Previous research indicates rural populations have a greater proportion of older adults compared to urban areas, yet lack the infrastructure to provide specialty care to this population.

It is estimated that more than 60 million family members provide some sort of informal care to an older adult relative. Of all of these family members, nearly 40% report spending 20 or more hours a week providing this unpaid care. Previous research has failed to examine how these family members feel about home modifications and technologies for their older adult relative. Finding ways to ease the burden of caring for older family members will significantly better the situations of many family relatives.

This dissertation aims to cover three areas.

1. Identify people at risk of suffering subsequent fall injuries. Find the average time between an initial fall injury and a subsequent fall injury, and find average time between an initial fall injury and death.

2. Examine the preferences of older adults living in a rural area towards various smart home technologies and home modifications.
3. Examine the preferences of family members of older adults regarding smart home technologies and home modifications.

## Introduction

Nearly one in six U.S. residents (49.3 million people) are over the age of 65 (as of July 1st, 2018).[1] The proportion of older adults in the U.S. is anticipated to grow to 22.1% of the total population by 2050 (roughly 87.8 million people).[2] This growing proportion of older adults in America is driven in part by the aging Baby Boomer population (born between 1946 through 1964), decreased birthrates among the generations which followed the boomers, and longer lifespans of Americans in general. Regarding increased lifespan, today, 65-year-olds today can expect to live longer than their counterparts prior to the 1950s. For instance, 65-year-olds born between the years 1900 and 1944 could expect to live an additional 11.9 years; comparatively, 65-year-olds born after 1945 can expect to live an additional 19.1 years.[3]

The continued growth of the American older adult population will have significant impacts on the healthcare system and on the economy. In advanced age, the effects of negative lifelong habits (i.e., smoking, lack of exercise, obesity) start to take their toll and many chronic diseases start to manifest. Seven out of ten deaths are due to chronic conditions, and $2.3 trillion are spent annually for related treatments.[4] Older adults with chronic conditions are also more at risk of suffering from unintentional injuries (i.e., unintentional falls, automobile accidents, etc.), and as a result many lose their independence and require additional care and support from healthcare professionals.[5,6] Costs associated with long-term care and assistive services range from $45,000 to over $100,000 per year depending on the type of care requested.[7] Given that the average income in the United States was $59,039 in 2017, paying for additional healthcare support may be out of reach for many families in the United States.[8]

With the proportion of older adults in the United States continuing to grow, it is inevitable that age-related conditions and injuries will become larger healthcare concerns. Because many older adults rely on government programs, including Social Security and Medicare, as the tax burden to keep these programs viable increases, policy makers and researchers will need to find new ways to keep healthcare costs down. This dissertation highlights some of the challenges the United States faces with respect to its aging population and explores ways in which older adults, and other people or organizations concerned for their safety, may be able to reduce their risk of injury, and subsequently reduce overall healthcare spending.

## Section 1: Financial Impacts of Advanced Aging

Understanding how the United States financially assists its older adult population is necessary to understand how the growing number of older adults will impact the existing system. This section briefly discusses two federal programs, Social Security and Medicare, which exist to aid older adults by providing financial support.

Social Security is the largest federal program in the United States. This program takes taxes from all working individuals and provides monthly payments to eligible citizens over the age of 65. In 2017, this program made up 36% of the federal budget.[9]

Nationally, nine out of every ten older Americans receives benefits from the Social Security program.[10] For the fiscal year of 2018, the United States government paid a record breaking $1 trillion in Social Security payments to older adult beneficiaries -- approximately $1,200-$1,800 dollars a month to nearly 62 million eligible individuals (including older adults and disabled individuals).[10,11] For approximately 65% of older adults in the United States, Social Security provides more than half of their yearly income.

Due to the increasing number of older Americans eligible for the Social Security program, the Social Security Administration (SSA) estimates the program will be financially unsustainable after the year 2034.[12] Due to lower overall birthrates, there are fewer Americans entering the workforce than there are leaving it. As a result, there will not be enough tax revenue to support Social Security beneficiaries at the same level we are able sustain currently.[12] A report from the SSA in 2019 indicates that the cost of the Social Security program is projected to exceed its total income (including interest) in 2020 for the first time since 1982.[13] Because more than half of all older adults rely on Social Security as a major source of financial support, decreased Social Security payments could be extremely detrimental.

In addition to Social Security, the federal program Medicare is also a large portion of federal spending, accounting for 14% of the federal budget, or roughly $582 billion dollars.[14] Unlike Social Security, Medicare funds will remain solvent – that is, able to pay 100% of the costs of hospital insurance coverage (known as Medicare Part A) – through 2029.[15] Past 2029, it is expected that payroll taxes and other revenue will still be sufficient to pay 88% of Medicare part A costs. To make up the other 12%, additional taxes and fees may be implemented to help bring Medicare part A back to full solvency. Nevertheless, providing various healthcare services to older adults is costly. At present, programs such as Social Security and Medicare provide much of the financial assistance older individuals need in regard to emergency-based healthcare. Due to the increased financial strain on government programs like Medicare part A caused by an increased number of older adults needing emergency services, finding ways to prevent injury will help alleviate financial burdens on older persons and their families.

Older adults living in the community may struggle with daily chores and other tasks to varying degrees. In order to aid these older adults without paying for expensive professional services, many family members and/or friends provide informal care to older adults. In 2009, more than 60 million family caregivers were providing unpaid care to older adults, at an estimated cost of $450 billion.[16] National estimates report that 40% of informal caregivers report high burden, meaning they spent more than 20 hours a week providing care to their older adult relatives.[17] As the proportion of older adults continues to rise, the need for family members to provide informal care will increase as well. As a side effect, the lost wages younger family members will suffer due to spending unpaid time caring for their older relatives may burden them financially.

Age-related conditions increase government spending, necessitate out-of-pocket expenditures at the individual level, and can require substantial time commitment from family members to provide informal care to older adults. As a result, finding ways to

address problems associated with aging will not only help reduce costs for both the US government and individual residents, but also help relieve the burden that family members have helping care for their older relatives.

**Section 2: Age-Related Health Problems**

Chronic diseases are becoming more prevalent in the nation's older adult population. Seven out of ten deaths among individuals aged 65 years or older are due to chronic diseases, and of the $3.65 trillion spent on healthcare in 2018, a nearly $1 trillion increase since 2010, 86% was used for the treatment of chronic conditions.[4] With the ever growing number of older citizens, costs for treating chronic conditions is expected to increase as well. Among all older adults living in the United States, approximately 80% of them have at least one of the following chronic conditions: cardiovascular disease, cancer, chronic respiratory disease, Alzheimer's disease, arthritis, diabetes, and chronic kidney disease.[18] It is estimated that 68% of all older adults have at least two chronic conditions.

Many older adults with chronic conditions report having a lower quality of life and life satisfaction compared to older adults without chronic conditions.[19–21] Decreasing the prevalence of chronic conditions would logically lead to an increase in quality of life among older adults in general, and reduce overall healthcare spending. With chronic conditions currently affecting four out of five older adults, treating and preventing these conditions would positively affect a significant proportion of older adults in the United States.

**Section 3: Fall Injuries**

In 2016, deaths from unintentional injuries were the seventh leading cause of death among older adults.[22] Among all unintentional injuries which required hospitalization, falls account for 55% of them.[23]

Falls are the leading cause of disability, morbidity, and death for adults aged 65 years and older.[24] In the USA, approximately one-third of all older adults experience falls every year.[25] Internal factors (poor vision, nutritional deficits, and frailty) as well as environmental factors (dim lighting and cluttered walkways) influence the risk of experiencing a fall in community-dwelling older adults.[26] Annually, among older adults who experience a fall, 31% of these falls result in an injury requiring medical attention, 10-15% result in fractures, and another 5% result in more serious soft tissue damage or head trauma.[27,28] Over 800,000 patients per year are hospitalized because of a fall injury, most often because of a head injury or hip fracture.[28] Prevention of falls, particularly within the home, has thus become a major public health concern.

It is estimated that more than 95% of all hip fractures among older adults are due to fall injury.[29] Each year, over 300,000 older adults are hospitalized for hip fractures.[30] Additionally, three-fourths of all older adults who suffer from hip fractures are women.[31]

Approximately 23% of all older adult fallers over the age of 70 die within a year of sustaining a hip fracture.[32] Risk factors for hip fractures include many age related problems such as weakening bones, poor vision, balance problems, and various chronic conditions.[33]

Treating hip fractures can be a costly endeavor. Direct medical costs for hip fracture surgery can range from $60,000 to $70,000 per individual, and national costs are estimated to range from $18 billion to $21 billion annually.[34] However, even with advances in technology and medicine, health outcomes including mortality rates and functional mobility have remained relatively unchanged since the 1970s.[32]

Falls are also the most common cause of traumatic brain injury (TBI) among older adults.[35] Annually, over 150,000 older adults are diagnosed with TBI as a result of falling.[36] Of these 150,000 individuals, 12,000 die as a result of a TBI.[36,37] Additionally, TBIs may have lasting effects on health; e.g., there is some evidence that moderate to severe head injury can lead to the development of cognitive decline and even Alzheimer's disease.[38] Generally, TBI is seen as a less severe injury compared to hip fractures; however, older adults who suffer from TBI as a result of falls have worse 12-month mortality and functional outcomes compared to older adults who do not suffer brain injury in their fall.[39] In 2015, it was estimated that the lifetime economic cost of TBI, among older adults including direct and indirect medical costs, was approximately $76.5 billion.

**Section 5: Home modification and smart home technology**

One of the most effective ways to reduce overall healthcare spending on unintentional injuries is the adoption of preventive measures. Exercise programs focused on balance, gait, and strength have been found to significantly decrease the risk of suffering a fall among older adults.[40–44] However, getting older adults to incorporate exercise into their daily routine is difficult. In 2017, the CDC's Behavioral Risk Factor Surveillance System reported that 66-72% of older adults over the age of 65 failed to achieve recommended activity levels (150 minutes of physical activity a week).[45,46] Additionally, a 2012 review reported a majority of older adults are overly sedentary; approximately 9-10 non-sleeping hours are spent in sedentary behaviors.[47] Because getting older adults to adopt exercise has been largely unsuccessful, research has also been conducted to examine the use of home modifications and smart home technologies as another way to reduce fall injury among older adults.

Various home modifications have been utilized and installed in homes for decades. Handrails, ramps, and adjusting furniture are examples of modifications that have been commonly implemented. The term "home modification" includes the removal of environmental obstacles (also known as home hazard reduction) or installations to the physical home environment with the express purpose of reducing falls or other physical injuries. Previous research has reported that home modifications and home hazard reduction practices are effective at reducing falls and injuries.[48–51]

The decision to modify one's home is a process for older adults and their families. Factors such as cost, independence gained, increased security, and increased safety have been reported to influence the decision-making process.[52–55] Some individuals are more in need of home modifications than others, and in some cases these modifications are paid for by government entities.[56–58] In all studies that examined satisfaction, older adults and their families had positive feelings towards the modifications.[52–55]

More recently, smart home technologies have made available to consumers that claim to increase factors including security, safety, and communication. Smart home technologies may be a cost-effective way of increasing safety and improving home care for older adults and the disabled. However, due to the relatively recent invention of these technologies (within the last 7-10 years), there are currently no studies which verify the efficacy of many smart home technologies and products.

**Section 6: Gaps in the literature**

The rapidly aging population in the United States will increase demands for a multitude of services. To date, treating chronic conditions and injuries among older adults is costly, and with America's growing older adult population, this burden will grow. With programs such as Social Security and Medicare providing much of the financial support that older Americans rely on for the treatment of age-related conditions and injuries, steps must be taken to ensure that all patients continue to receive quality care and that both programs remain financially solvent. Apart from cost, the physical discomfort, anxiety and stress, and other burdens that can arise after suffering a serious fall injury highlight the need for older adults, and Americans in general, to take preventive measures to reduce their risk of falling.

To date, there are several gaps in the literature. First, research conducted on fall-related injuries sustained by older adults reporting to the emergency department lack information about comorbid conditions such as frailty and malnutrition, as well as other factors including socioeconomic status, urbanicity, and disposition after their first visit.[59] These risk factors have been associated with fall related injuries in previous studies, but no study has examined these conditions together. As mentioned previously, more than 68% of older adults have more than one comorbidity. Considering more than half of all individuals with chronic diseases have multiple conditions, it is important to consider their collective effects on rates of falls rather than study the effects of a single chronic condition and its effect on the risk of fall injury. Secondly, although research has shown that experiencing one fall increases the risk of experiencing another, there have been few attempts to understand other risk factors, apart from various comorbid conditions, that predict subsequent falls among older adults.

Thirdly, research focusing on rural populations of older adults is severely lacking. Various reports indicate that rural populations of older adults are quite different than their urban peers in significant ways. In rural areas, residents tend to be older on average, compared to urban areas, 15.7% of rural populations are aged 65 and older compared to 13.0% in urban areas.[60] The CDC also reports that older adults in rural areas have a

higher burden of chronic disease and a greater chance of dying a preventable death compared to their peers in urban areas.[61] Rural areas have higher rates of poverty among their older adult populations, leading to them being less likely than their urban counterparts to leave their homes when they retire and relying more heavily on private transportation.[62] Research should be concerned with addressing this disparity in health status between rural and urban dwelling older adults.

With respect to the adoption of home technologies among older adults, there is a lack of research examining how older adults feel towards these potentially safety-enhancing devices. Existing research has relied on the Technology Adoption Model (TAM), which postulates that the adoption of technology is dependent on the technology's perceived usefulness and perceived ease of use.[63,64] However, existing research has only examined technology adoption in the context of leisure or entertainment uses. Because smart home technologies promote safety and security, these devices may have higher perceived usefulness, and may be better poised to be adopted by older adults.

Additionally, the existing literature regarding the adoption of technology among older adults fails to consider the preferences of their adult children or relatives (if they have any), who may have some influence on the behaviors of their older adult parents or relatives. However, research focused on how the preferences of family members affect the decision-making process is under-studied. As mentioned previously, more than 60 million family caregivers provide unpaid care to older adults, and approximately 24 million spend more than 20 hours a week administering care.[16] Finding ways to ease the burden of caring for older family members will significantly better the situations of many family relatives.

**Section 7: Research aims and objectives**

The three studies that make up this dissertation aim to address aforementioned gaps in the literature in the following way:

1. The first study will examine risk factors (including malnutrition, previous chronic disease diagnoses, neighborhood-level disadvantage, urbanicity, and other individual- and area-level characteristics) for subsequent fall-related injury and death among older adult fallers.
2. The second study aims to understand the preferences of rural older adults towards home modifications and smart home technologies to determine whether they perceive value or benefits in utilizing these technologies.
3. The third study aims to examine preferences among *family members* of older adults with respect to the adoption of technologies and home modifications for their older adult relatives.

Conducting studies to address these research aims will benefit the field in the following ways. Addressing the first aim will help identify various risk factors that have

not been studied or have not been studied at the same time as other risk factors, in regards to fall injury. This study will also help determine the time between a person's first fall and a subsequent fall or death, helping researchers and clinicians develop programs and interventions which can be implemented before another unintentional injury occurs.

Addressing the second research aim will help identify attitudes towards home modifications and smart home technologies among rural older adults. As the primary group for which these technologies are being developed, understanding how older adults value these products will help determine which technologies and products are worthy of further investigation.

Lastly, addressing the third research aim will identify the preferences of adult children or caretakers of older adults towards various smart home technologies and home modifications. Because the use of technology is higher among this younger group of adults compared to their older relatives, they may have influence as to whether older adults ultimately accept or reject technologies for installation in their home.

Together, addressing these research aims will help researchers and clinicians identify older adults at risk for suffering from subsequent fall injury, and build a case for the appropriateness of including smart home technologies as part of an injury prevention strategy based on the preferences of older adults and their family members. With the proportion of older adults increasing every year, the number of fall-related injuries and total money spent on treating fall injuries will inevitably increase. Decreasing the number of preventable fall injuries among older adults is a serious public health challenge, and the research presented in this dissertation aims to help identify pathways to lower rates of subsequent fall injuries in this population.

## Study 1: Repeat fall injury and subsequent death among older adults: A statewide longitudinal study

### 1. Background

As of July 1st, 2016, nearly one in six U.S. residents (15.6%, or 49.1 million people) were over the age of 65.[1] This proportion is anticipated to grow to 22.1% by 2050.[2] Among older adults, falls are the leading cause of disability, morbidity, and death:[24] each year, approximately one-third experience a fall.[25] In 2016, 29,668 U.S. residents at or older than 65 died as the result of a fall. Half of all falls among older adults occur either at home or while carrying out daily activities.[65] The cost of treating fall related injuries is estimated to be 29.4 billion USD per year.[66]

Falls are associated with a range of adverse outcomes, including poorer quality of life and higher levels of anxiety;[67–69] physical decline, depression, social isolation and feelings of helplessness;[25,69] increased risk of a subsequent fall;[70] and increased risk of death.[29,71] Indeed, it is estimated that 30% of fall patients have a subsequent non-fatal fall within one year of their initial fall,[70,72] potentially exacerbating feelings of anxiety and fear and thereby contribute to declining health,[25,67] and that 31% die within three years following an initial fall.[59] Understanding the incidence of and risk factors for repeat falls and death is important for designing better intervention programs and enabling accurate patient risk stratification.

The World Health Organization (WHO) has identified five broad categories of risk factors for fall-related morbidity and mortality in older age: biological, behavioral, economic, environmental, and social characteristics.[73] In studies which use hospital record data to study falls among older adults, the focus has largely been on biological and behavioral predictors. Previous studies have reported, for example, that biomedical factors such as physical frailty, medication use, poor vision, nutritional deficits, and chronic disease predict fall-related injury morbidity and mortality,[5,26,59,68,71,74,75] as do behavioral factors such as sedentary lifestyles and mental and substance use disorders (side effects of which can include disorientation and dizziness). [26,76–78]

Nevertheless, notable gaps in the literature remain. Many prior studies rely on data from single hospitals or a few hospitals in a small geographical region, limiting their generalizability.[70,72] Prior studies also often use self-reports of falls rather than objectively measured incidence. Furthermore, potentially important risk factors are often left out of analysis: For example, while studies from other countries suggest that residence in an urban (vs. rural) area is associated with increased risk of fall injury among older adults,[79,80] the role of urbanicity is poorly understood in U.S. contexts, especially with respect to repeat fall injury and death.[81] At present, prior research indicates that rates of unintentional fall injury are increasing nationally, however differences between rural and urban populations remains unreported.[82] Race/ethnicity is understudied as well, Asian/Pacific Islanders (one of the fastest-growing segments of the older population[83]) and Hispanic populations have been excluded from prior analyses, which primarily focus

on the health outcomes of White Americans; yet research suggests that race/ethnicity is an important determinant of fall injury-related morbidity. [84]

This study aimed to estimate rates of objectively assessed repeat fall injury and related mortality among older adults using population-based data from California, a large and ethnically diverse state home to nearly 5 million individuals aged ≥65 years.[85] The study additionally aimed to provide a comprehensive analysis of how multiple risk factors – including biological, behavioral, and social characteristics – affected older adults' fall outcomes.

## 2. Methodology

Data from the California Office of Statewide Health and Planning and Development's (OSHPD) restricted emergency department (ED) data and hospital patient discharge data (PDD) files for the period 2009-2012 were utilized for this study. The ED dataset contains records of patients treated in a licensed emergency department and discharged or transferred to another facility. The PDD dataset contains records of all patients admitted for treatment in an inpatient setting, including emergency department patients directly admitted to that facility.

The cohort was defined as all adults aged ≥65 years who utilized emergency department services in 2010 and had a valid California zipcode (Patients admitted to the hospital from an ED were also included for analysis). We excluded older adults with an ED or inpatient record indicating a fall injury in 2009 (n=87,476), to avoid including individuals with a recent fall injury.[29,71] To track each patient through time, OSHPD's "record linkage number" was utilized. RLNs are encrypted social security numbers, which allows researchers to track individuals' utilization of any hospital-based service within the state of California both retrospectively and prospectively. Of the 1,190,444 total visits to the ED made by older adults in 2010, only visits with a valid RLN present were eligible to be included in the study (96.4%).

### *2.1 Case definition*

Fall injuries were identified using International Classification of Disease-9$^{th}$ revision, Clinical Modification (ICD-9-CM) external cause-of-injury codes (E-codes).[86] Consistent with prior literature,[78,87,88] patients were classified as having experienced a fall if any of the 24 ICD-9-CM codes at their visit was E880.xx - E888.xx. A full description of these codes can be seen in **Table 1.1**. A patient's first visit for a fall injury in the year 2010 was considered their index visit. For patients without a fall-related visit in 2010, their first ED or hospital record for the year was considered their index visit. A list of the ten most common external injury codes reported among fallers at index visit can be found in **Table 1.2**.

### *2.2 Dependent Variables*

The first outcome of interest was the patients' total number of visits to the ED or hospital for fall injuries following their index visit. Repeat fall visits were defined using

the same criteria as the index fall (E880.xx - E888.xx). Follow-up began the date after each patient's index visit presentation and ended on December 31st, 2012.

The second outcome of interest was patient death following the index visit. Patients whose index visits resulted in death in the ED or hospital were excluded from follow-up analyses (n=3,226). Patient death information, including the date of their death and the underlying cause of the death, was provided by the California Department of Public Health Vital Records office, which maintains death records for all state residents (excluding the <1% who die out of state each year). The death record and ED/PDD datasets were deterministically linked using patient social security number (SSN) and birthdate.[89] Patient all-cause mortality was recorded as a bivariate variable which denotes death over the follow-up period.

*2.3 Covariate and risk factor variables*

Multiple patient- and area-level variables, described below, were included in the analysis. These variables were treated as covariates in analyses comparing individuals who had a fall-related injury in 2010 (referred to as "fall patients") to individuals who did not have a fall injury in 2010 (referred to as "other patients"), and as predictors in analyses examining risk factors for subsequent falls and death among the sub-population of fall patients.

Patient sex was classified as male or female. Age was categorized into 5 groups based on the patient's age at their index visit: 65-69 years, 70-74 years, 75-79 years, 80-84 years, and 85 years or older. Patient race/ethnicity was based on information provided at the patient's index visit and grouped into 5 categories: White, Black, Hispanic, Asian, and Other. Patient insurance status was based on the expected payer at index visit and grouped into 5 categories: self-pay/no insurance, private, Medicare, Medicaid, and other.

The Charlson Comorbidity Index (CCI) was utilized to construct a comorbidity score for each patient at his or her index visit in 2010.[90] The CCI is a method of categorizing chronic condition comorbidities, based on *ICD-9-CM* diagnosis codes, and includes the following chronic conditions: heart diseases, peripheral vascular disease, cerebrovascular disease, dementia, rheumatic disease, peptic ulcer disease, liver disease, paraplegia and hemiplegia, renal disease, cancer, and AIDS/HIV. Each comorbidity category has an associated weight (from 1 to 6), based on the adjusted risk of mortality or resource use, and the sum of all the weights results in a single comorbidity score for the patient. A score of zero denotes no presence of chronic comorbidity, scores between 1 and 2 denote a small/slight disability due to chronic conditions, scores between 3 and 4 denote moderate disability due to chronic conditions, and scores of 5 or more denote major disability due to chronic conditions. CCI score was included in the analysis to control for chronic disability, with the assumption that more chronically ill individuals would be at higher risk of falling.

We also created a variable indicating malnutrition status at index visit (present vs. absent), which is associated with a variety of negative health outcomes and death. Comorbid malnutrition was identified using the *ICD9-CM* diagnosis codes 260-263, 278, 283, 799.xx, and V850, comprising conditions like kwashiorkor, protein-calorie malnutrition, morbid obesity, and BMI $\leq$19.[91]

Substance use disorder (SUDs) diagnoses, including alcohol and drug use, were identified at index visit using Clinical Classification Software (CCS) codes. CCS codes aggregate *ICD-9-CM* diagnoses into discrete, clinically meaningful categories.[92] CCS codes 660 and 661 were used to identify alcohol and drug use, respectively. A large number of older adults have SUDs, and previous research has indicated that SUDs are related to increased injury and hospitalization risk in older adults.[93,94]

Patient disposition at index visit was categorized as discharged home, discharged to a skilled nursing facility or long-term care facility, discharged to another inpatient health institution (i.e., medical facility with hospice care, psychiatric hospital, federal healthcare facility, etc.), or other. The 'other' category included discharged to prison, left against medical care, transferred to a disaster alternative care site, etc.; these outcomes were rare. We hypothesized that sicker and more injured older adults would be transferred to skilled nursing homes or long-term care facilities where, under more active care, patients should be at reduced risk of subsequent fall injury and death compared to those discharged home.

Patients' prior emergency department records from 2009 were linked to their 2010 record to construct covariates related to prior ED utilization. For each patient, a variable totaling all ED visits they made for any reason in the year 2009 was created.

Urbanicity was defined using the U.S. Department of Agriculture's Rural-Urban Commuting Areas (RUCA) 2010 geographic taxonomy, Version 3.10.[95] The RUCA database classifies U.S. census tracts using measures of population density, urbanization, and daily commuting. The classification uses a scale (1-10) to define census tracts as metropolitan, micropolitan, small town, and rural commuting areas based on the size and direction of the primary (largest) commuting flows. For this study, we collapsed the four categories into three: metropolitan, micropolitan, and small town/rural. Urbanicity was included in the analysis in order to control for variation in access to healthcare resources in rural vs. metropolitan areas.[96]

Area-level characteristics derived from the U.S. Census were used to assess economic disadvantage in patients' residential zip codes. Zip code economic disadvantage was defined using a standardized composite of percent of families below poverty level, unemployment rate, and median household income (reverse-coded), based on 2010 estimates supplied by GeoLytics.[97,98] This continuous variable was collapsed into quartiles, with the highest quartile corresponding to highest level of disadvantage. Area-level characteristics were controlled for because we hypothesized that patients from more disadvantaged areas would have less access to health resources and therefore be more likely than those in wealthier areas to have subsequent fall injuries and all-cause mortality over the follow-up period.

*2.4 Statistical analysis: Subsequent fall and mortality outcomes*

To compare the rate of subsequent fall-related injuries, and rates of death, among fall patients vs. other patients, we calculated incidence rate ratios using robust standard errors and an offset term to account for variation in follow-up time across patients.[99] The use of robust standard errors was used to account for multiple visits by an individual.

To identify the risk factors associated with two-year subsequent fall injury and mortality among fall patients, the data was restricted to patients who had a fall-related

injury in 2010. Incident rate ratios using robust standard errors were calculated to explore the relationship between predictor variables and the outcome (subsequent fall injury or death). For each analysis described above, two models were calculated: (1) a *bivariate model*, which examined the relationship between each predictor variable and the outcome separately, and (2) a *multivariate model*, which included all predictor variables in the model together. Stata v14 (StataCorp, College Station, TX) was used for all analyses.

## 3. Results

A total of 1,108,815 older adults made visits to the ED or hospital in 2010 for any cause and were eligible for inclusion in the analysis. A total of 174,220 (15.7%) of these patients had a fall-related injury in 2010; all others (n=934,595) were included in the non-fall comparison group. Basic demographic information for the analytic sample can be found in **Table 1.3.** Among other patients, the top five medical complaints at index visit were chest pain (4.3%), osteoarthritis (3.9%), cardiac dysrhythmias (3.4%), urinary tract infections (3.1%), and pneumonia (3.0%).

A majority of fall patients were female (66.6%), White (71.4%) and on Medicare (66.0%). Fall patients tended to have lower rates of malnutrition and lower CCS scores compared to other patients: rates of malnutrition at the index visit were 3.3% among fall patients and 5.0% among other patients, and 52.3% of fall patients had a CCI score of 0 (indicating no presence of chronic comorbidity) compared to 39.6% among other patients. However, fall patients were more likely than non-fall patients to have a previous ED visit in the past year for any reason (44.8% compared to 39.7%).

Fall patients had higher incidences of both subsequent fall visits and death following the index visit in 2010 compared to other patients, as shown in **Figure 1.1**.

*Fall patients versus other patients*

Among the total sample (1,108,815 individuals), 18.2% had a subsequent fall, and 27.7% died, following their index visit in 2010. Among the 174,220 fall patients, 61,013 (35.0%) had a subsequent fall (average of 1.68 falls over the follow up period) and 60,942 (34.9%) died within the follow up period. Among fall patients who suffered a subsequent fall, the average time between the index and first subsequent fall was 0.87 years (SD=0.76). And among fall patients who died during the follow up period, the average time between their index visit and death was 1.38 years (SD=1.09).

Among the 937,736 other patients, 141,322 (15.0%) had a subsequent fall injury visit (average of 1.39 falls over the follow up period) and 246,532 (26.3%) died within the follow up period. The average time between the index visit and first subsequent fall was 1.49 years (SD=0.65). Among other patients who died during the follow-up period, the average time between their visit and death was 1.32 years (SD=1.13).

In bivariate analyses, the rate of subsequent fall injury visits during follow-up was 3.44 times higher (95% CI: 3.40, 3.47), and the rate of death was 1.36 times higher (95%

CI: 1.35, 1.37), among fall patients when compared to other patients. After controlling for all covariates, fall patients' rate of subsequent fall visits was still nearly three times higher (RR: 2.96, 95% CI: 2.92, 2.99), and their rate of death was 22% higher (RR: 1.22, 95% CI: 1.21,1.24), than those respective rates among other patients.

*Predictors of subsequent fall injury among fall patients*

We then restricted our analysis to patients with a fall-related injury in 2010. In the fully adjusted model, women had slightly higher rates of subsequent falls compared to men (RR: 1.04; 95% CI: 1.03, 1.06). All age groups older than the 64-69 comparison group had increased rates of subsequent falls. Patients with more chronic conditions also had increased rates of subsequent fall injury: patients with CCI scores ≥5 had 1.27 (95% CI: 1.24,1.29) times higher rates of subsequent fall injury compared to patients with CCI scores of zero. Full results from this model, as well as the bivariate analysis, can be found in **Table 1.4**.

*Examining predictors of subsequent death among fall patients*

Among fallers, in the fully adjusted model, females had lower rates of death compared to males (0.64 (95% CI: 0.63,0.65)). Each age group older than the comparison group had increased rates of death following a fall injury, with those aged ≥90 years having 4.87 (95% CI: 4.67,5.07) times the rate of death compared to those aged 65-69. Patients with higher chronic comorbidity scores had increased rates of death: patients with CCI scores between 3-4 had a 2.09 (95% CI: 2.00,2.19) times increased rate of death compared to those with CCI scores of zero. Individuals with an index diagnosis of malnutrition had a 1.55-fold (95% CI: 1.49,1.61) increased rate of death compared to individuals without a malnutrition diagnosis. Full results from this model, as well as the bivariate analysis, can be found in **Table 1.5**.

## 4. Discussion

Fall injuries among older adults are a serious public health concern. In this large, longitudinal, population-representative study, one in six older adults who presented to the ED or hospital in 2010 were there for a fall-related injury, and multivariate analyses demonstrated that having a fall injury increased the rate of subsequent hospital-treated fall injuries by 3-fold, and the rate of death by 22%, compared to non-fall patients. Of all the patients who presented to a hospital for a fall-related injury in 2010, we found that 31.5% died within 3 years. These findings are very similar to a previously published study which reported a 3-year mortality rate of 31.1% following an initial ground-level fall.[59]

We found that female fall patients, compared to males, had higher risk of experiencing a subsequent fall but lower risk of death over the follow-up period. Prior

studies report that women suffer more serious fall injuries, hip fractures, contusions, and lacerations, compared to men.[100] The lower rates of death among women may be due to higher overall rates of death among males,[101] leading to fewer males in the at-risk population for having subsequent falls, or potentially to females taking more precautionary measures to prevent future falls after experiencing an initial fall injury.

With respect to race/ethnicity, when compared to non-Hispanic Whites, all minority groups experienced lower rates of subsequent fall injury and death. Furthermore, Asians/Pacific Islanders had lower rates of subsequent fall injury and death compared to Whites, and lower than both Blacks and Hispanics. The lower rates of subsequent fall injury among racial/ethnic minority populations compared to non-Hispanic Whites may be due to differences in how minority populations care for their older family members. Previous research indicates that compared to whites, African-Americans are more likely to receive unpaid help from family members, both immediate and non-immediate.[102,103] Furthermore, a 2001 survey conducted by the Association of American Retired Persons (AARP) found that Asians (42%) were most likely to care for an older relative, followed by Hispanics (34%), Blacks (28%), and Whites (19%).[104] In contradiction with previous research, we found that Hispanics had lower rates of subsequent fall injury and death compared to Whites. Previous research using data from the Health and Retirement Study reported that rates of falls among Hispanic populations did not significantly differ from Non-Hispanic Whites.[84] We believe that this discrepancy may be due to our larger and more population-representative sample, as well as cultural differences in regards to older adult care, as described earlier.

Higher CCI scores predicted higher rates of both subsequent fall and death. However, those with CCI scores of 3-4 were at higher risk of subsequent fall compared to those with CCI scores of 5 or more. This association may be due to sicker (individuals with more chronic conditions) needing more care, and thus being more likely to already live in protected environments with higher levels of safety.[105] Being diagnosed with malnutrition at the index visit was associated with decreased rates of subsequent falls and with increased rates of death during the follow up period. The reason for the seemingly protective effect against subsequent fall injury may be due to malnourished individuals being more likely to be removed from their previous home environment into places with caretakers or into nursing homes, with higher levels of safety.[105–107] This finding has important intervention implications, as studies indicate that rates of malnutrition may be as high as 20% among older adults living in the community.[107,108] Malnutrition diagnoses are present in as many as 40% of hospital visits made by older adults.[107,109]

Being diagnosed with substance use disorders predicted higher rates of subsequent fall injury, but not death. This finding is in line with previous research which found that SUDs are associated with various side effects, including disorientation and dizziness, which have been related with increased risk of falling.[78] An estimated 2.8 million older adults had a SUD in 2006, and that by 2020, that number will have increased to 5.7 million.[93] Some SUDs in older adults may be caused by the use of multiple prescription medications – 37.1% of older men and 36% of older women report

using at least 5 prescription medications concurrently.[110] Our study data did not include information on medication use, so we could not examine this risk factor in detail.

Being discharged to a skilled nursing facility or to a long-term care facility was associated with lower rates of subsequent fall injury but increased rates of death over the follow up period. Both skilled nursing facilities and LTC facilities are protected environments with higher levels of safety. Reassuringly, the increased level of care given to older adults in these facilities seems to protect against further fall injuries.[105–107]

With regard to fall patients having fewer chronic comorbidities and lower rates of malnutrition compared to other patients, we were unable to find any previous research which may explain this pattern. Of note, fall patients had higher rates of past-year emergency department service utilization, so it does not reason that they are healthier than other patients. The pattern may be present because, in busy emergency departments, patient evaluations for malnutrition and other chronic conditions may not be conducted when a patient comes in requiring immediate medical attention for a serious fall-related injury.

Our analyses found no statistically significant association between living in small town/rural area and subsequent fall or death among older adults. However, there was a significant, but slight, increase in both subsequent falls and death (among fall patients) among older adults living in micropolitan environments compared to metropolitan environments, even after controlling for other covariates. This association may be due to increased access to care and services in metropolitan areas compared to micropolitan areas. However, if this were the case it would reason that the rates of subsequent falls and death would be even higher in small town and rural areas, which we did not observe. Future research may want to examine why these associations between subsequent falls, and death, and patient urbanicity differ.

### *Limitations*

This study has several limitations. First, we did not have access to any information about fall injuries treated outside of hospital and emergency settings (i.e., urgent care, outpatient clinics, etc.). Estimates regarding the number of older adults who had fall injuries are thus under-estimated. Second, we are unable to account for patients who moved out-of-state during the follow-up period, who were treated at non-Californian EDs or hospital facilities, or who died outside of California, and thus could not be followed. This would have resulted in overall under-estimates of ED and hospital service utilization; the degree to which such loss to follow-up differed between fall patients and comparison patients is unknown, but likely minimal. The California Department of Public Health Vital Records office estimates that fewer than 1% of Californian residents die out of state each year, therefore any bias in our mortality estimates due to this limitation should be minor.[89] Estimates from the 2010 American Community Survey indicate that of the roughly 5 million Californians over the age of 65, only a small percentage moved out of the state.[111]

## 5. Conclusion

This population-based analysis demonstrates that rates of fall-related injuries (including repeat injuries) and death are high among older adults. Rates for repeat fall injury are especially elevated among women, non-Hispanic Whites, individuals with comorbid medical conditions, residing in micropolitan areas, who had diagnoses of physical and substance-use comorbidity, prior ED utilization, and who live in lower-SES areas. Our estimates are based on a highly reliable data source, increasing the strength of the study. With the increasing number of Americans aged over 65, addressing biological and behavioral risk factors, including malnutrition, frailty, and substance use, to name a few, may help reduce fall injuries among the older adult population. These findings underscore the need for better secondary prevention among older adults seen in hospital settings for fall-related injuries and identify subgroups who may benefit most from public health interventions.

## Study 2: Preferences in home modifications and technologies among family members of older adults: A discrete choice experiment

### 1. Background

Today, just over fifteen percent of all U.S. residents are over the age of 65.[1] For this population, falls are a leading cause of disability, morbidity, and death.[24] In the USA, approximately one-third of all elderly adults experience falls annually.[25] Every year, among older adults who experience a fall, 31% experience an injury requiring medical attention, 10-15% result in fractures, and another 5% result in more serious soft tissue damage or head trauma.[27,28] Apart from the physical injuries sustained by falling, older adults who experience a fall also suffer from significantly decreased quality of life and increased levels of anxiety.[68] Older adults who fall report feelings of embarrassment and fear, generally correlated with the severity of their injury.[67,69] It is estimated that just under 30% of fallers have a subsequent fall within 1 year of their initial unintentional fall.[70,72] These subsequent falls have many of the same outcomes in regards to physical injury, but oftentimes exacerbate feelings of anxiety and fear which are related with declining health.[25,67]

#### *1.1 Preventing further injury- Long Term Services and Support (LTSS)*

In 2016, the U.S. Department of Health and Human Services estimated that 52% of elderly individuals will need some sort of Long Term Support Services (LTSS) at some point in their lives.[112] LTSS encompasses services including assisted living, nursing home care, and long-term care; and can cost anywhere from $45,000 to over $100,000 USD per year.[7] Research indicates that 30% of Americans underestimate the cost of LTSS, and even more underestimate how likely it is they will need LTSS when they get older.[113,114] One way to reduce the cost of LTSS is to rely on unpaid care from family members or friends, commonly called informal care. Informal care is defined by the AARP as being voluntary or unpaid care provided to older adults or those with disabilities by family members or friends over the age of 18.[17] In 2009, more than 60 million family caregivers provided unpaid care, valued at $450 billion in lost wages from the labor force.[16] With the proportion of older adults expected to double by 2050, it is anticipated that more people will have to leave the workforce to care for elderly relatives and friends, which will negatively affect household incomes and the economy.[17]

#### *1.2 Preventing further injury: The use of home modifications and smart home technology*

A much more popular alternative to LTSS is “aging in place.” Aging in place is defined as “the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level.”[115] Numerous studies report that people prefer to “age in place” because it enables older people to maintain independence, autonomy, and connection to social support, including friends and family.[116–118] Facilitation of independent living among community-dwelling older adults is supported by policy makers, health providers, by many older people, and various

national and global organizations including the Centers for Disease Control and Prevention and the World Health Organization.[119]

Numerous technology companies including Google, Samsung, Amazon have started investing heavily in technologies designed to increase the independence of older adults living in their own home.[48–51] Even with current research on their efficacy scarce, national organizations like the AARP frequently recommend these products to their readers.[120,121]

The term "home modification" includes the removal of environmental obstacles such as furniture, rugs, etc. (also known as home hazard reduction) or installations to the physical home environment with the express purpose of reducing falls or other physical injuries.[122] For the purposes of this paper I will use the term home modification to describe installations or additions to the home environment (including technology), and home hazard reduction to describe the removal of items from the home environment. For the purposes of this paper, the term "smart home technologies" refers to internet-connected devices and other technologies that automate home system (thermostats, security, etc) or monitor people.[123]

Aging in place safely includes, by necessity, prevention of fall-related and other injuries. Studies which examined the effectiveness of home hazard reduction strategies report conflicting findings, some studies indicate that the practice is not very effective at reducing injury unless a non-home hazard reduction (i.e. physical exercise, skills acquisition classes, etc) intervention is also implemented.[40–44] However, other studies report that installations to the home environment were shown to be effective at reducing falls and injuries regardless of whether a non-installation-based home modification component was present.[48–51]

To date, academic research on the effectiveness of smart home technologies is limited. The majority of research on smart home technologies examines the machine learning algorithms used to help the technologies interact with their users. Few studies have examined how these technologies can reduce injuries and increase independence. Despite this, private companies and organizations like AARP have championed technologies such as indoor and outdoor security cameras, , automated lights, voice-activated devices, and wearable health monitors as promoting older adults' safety and independence.[120,121]

*1.3 Attitudes Towards Modifications and Smart Technology*

Previous studies indicate that factors such as cost, level of independence gained, and level of control play are important to older adults as they decide how to best modify their homes.[52–55] Different levels of need vary per individual and in some cases, home modifications are paid for by government entities.[56,57,124] Previous studies indicate that elderly individuals and their families have positive attitudes towards modifications paid for by government entities.[52–55] These previous studies emphasized that special care should be taken to include elderly individuals in the decision-making process and ensure that personnel installing the modifications are respectful and courteous towards the homeowners.

The literature also reports that continued independence is also important to older adults.[53] Studies indicate that older adults were more willing to modify their home environment and remove identified hazards if it meant staying in their homes. On average, the homes of older adults have 13 hazards in the environment, and those compared to whites, racial/ethnic minorities had five more problems on average compared to White individuals.[54] Research also indicates that older adults prefer home modifications which increase their ability to perform various activities of daily living.[56]

Data from the 2011 National Health and Aging Trends Study indicates that Hispanic and Black Americans are less likely than White Americans to install safety modifications such as grab bars and bath seats.[55] These disparities may be related to English language proficiency (defined as ability to speak and understand English), as the research team reported that individuals with self-reported moderate to poor proficiency were less likely to have installed any home modifications compared to those who self-reported being fluent in English.

Research concerned with the views and preferences of older adults considering home modifications lack nuance in several areas. Studies to date have not addressed what factors older adults value when thinking about home modifications or smart home technologies -- for example, do they consider the preferences of their children, worry about personal privacy, or value independence above either of those? Additionally, all studies examining the attitudes of older adults towards installations to the home environment were done in non-U.S. countries, where the cost of the installation of home modifications is paid for by local and national governments. In contrast, in the United States, individuals generally pay for any modifications themselves. How older adults in the U.S. weigh cost considerations when deciding whether to install home modifications thus remains largely unknown

*1.4 The Technology Adoption Model (TAM)*

A variety of theoretical frameworks attempt to explain trends in technology adoption among older adults. The Technology Acceptance Model (TAM) postulates that the adoption of technology is a function of two person-level beliefs: perceived usefulness, and perceived ease of use.[125] The TAM framework is often utilized to examine influencing factors that lead individuals to adopt or reject technological devices. Studies have found that a lack of both perceived usefulness and perceived ease of use deters older adults from using new technology.[63,64] Other, more complex models based off of the TAM indicate that differences in sex play a role in technology adoption as well, with males tending to adopt technology based on its perceived usefulness while women were more strongly influenced by the technology's perceived ease of use.[126]

Psychological determinants have also been shown to affect the adoption of technology by older adults. Anxiety-related factors, such as technophobia (the reluctance to adopt or use technology due to a psychological aversion against it) is theorized to be a main barrier for computer use among the elderly.[127,128] In contrast, attributes such as self-efficacy may facilitate the adoption of technology. Studies indicate that previous

experiences with technology led to higher levels of computer self-efficacy, and in turn lead to decreased anxiety and increased technology use.[129,130]

Research on the effectiveness of smart home technologies is limited, and studies that utilize the TAM have focused primarily on the use of internet-based applications for leisure or skill acquisition, rather than home safety. With the possibility of smart home technologies being able to increase independence and decrease injury, would older adults be interested in adopting such technologies even if their perceived ease of use is low? Additionally, for older adults with low self-efficacy in regards to technology use, would they be more inclined to adopt smart home technologies if such adoption meant more easily aging in place?

*1.5 Rural older adults: An under-researched population*

Estimates from the 2011-2015 five-year American Community Survey indicate that rural areas contain 19.3% of the U.S. population (about 60 million people) but covers 97% of the land area.[131] In rural areas, residents tend to be older on average, compared to urban areas, 15.7% of rural populations are aged 65 and older compared to 13.0% in urban areas.[60] The CDC also reports that older adults in rural areas have a higher burden of chronic disease and a greater chance of dying a preventable death compared to their peers in urban areas.[61] Older adults in rural areas also have higher rates of poverty, leading to them being less likely than their urban counterparts to leave their homes when they retire and relying more heavily on private transportation.[62]

Because many retirees are choosing to move to rural destinations and keep their independent lifestyles, many rural counties are effectively becoming retirement communities.[21] However, these communities have fewer options for geriatric care teams and accommodations specifically designed for older adults, and many rural communities have been designated as being medically underserved.[132]

The increased levels of poverty, decreased access to medical care and services, and increased risk of preventable injury and death highlight how older adults living in rural areas are greater need for additional research and support compared to their urban living peers. Despite the fact that older adults in rural areas may have a higher need for home modifications, home hazard reduction, and smart home technologies, due to their distance from services and care options, previous research has almost exclusively examined preferences regarding installations and technologies among urban older adults, leaving a gap in our understanding of an important and vulnerable population.

*1.6 Research Design*

This study utilized a guided, semi-structured interview approach to examine attitudes towards home modifications and safety technology among older adults. The purpose of this study was to examine, among older adults living in a rural area, feelings towards smart home technologies and home modifications. The study was also designed to inform a survey aimed at gauging the preferences and feelings of the adult children of older adults towards home modifications and smart home technologies.

This study was conducted in Mariposa County, which is located in central California. In 2017, the United States Census Bureau estimated that 17,569 people lived in Mariposa County, with 27.0% of residents being aged 65 or older. 80.1% of residents were reported as being Non-Hispanic White, 1.1% African-American, 3.3% Native America, 1.8% Asian, and 11.4% Hispanic or Latino. The median household income was $51,385, and 15.2% of the population was reported as living in poverty. In 2006, the most recently updated, the Health Services Resource Administration designated Mariposa County as being a medically underserved county.[96]

Prior to beginning this research project, Institutional Review Board (IRB) approval was received from the University of California, Merced.

## 2. Methodology

For this project, the target population was community-dwelling older adults living in a rural location. Participants were identified and recruited through community contacts at a senior center located in a rural town in Mariposa County. We gained access to this population through previously established relationships and partnerships with community and institutional stakeholders. Potential participants were approached at the senior center and asked to participate. Individuals who wanted to participate walked with the interviewer to a private room located in the senior center for the interview.

After collecting informed consent from each participant, demographic information was gathered, including age, sex, marital status, number of children, type of home lived in, whether they had long term care insurance, and whether they had ever had a fall. Activities of Daily Living (ADLs) and Instrumental Activities of Daily Living (IADLs; both defined below) were assessed using standard protocols that were read to the participants.[133,134] Lastly, participants were asked about whether they had (1) installed or purchased, (2) thought about installing or purchasing, and (3) if they have heard of the following home modifications and technologies: outdoor cameras, ramps, automated lights, indoor cameras, robotic vacuums, grab bars near the toilet, railings in the shower, seats in the shower, Life-Alert and smartwatches, voice activated devices, and self-driving cars. These items were chosen (except for the self-driving car) because they are marketed towards consumers as safety devices and/or equipment.[135] Because the ability to drive is an IADL measure which can potentially affect several other IADLs (ability to shop by themselves, obtaining medications, etc.), we wanted to gauge whether self-driving vehicles would be of interest for older adults. Study participants were given a $20 gift card to a general merchandise store in appreciation of their time.

### *2.1 Assessing Biological Risk Factors: ADL's and IADL's*

The "activities of daily living" (ADL) and the "instrumental activities of daily living" (IADL) are two measures used to clinicians to help identify a person's level of disability.[133] Together, these tools help to determine whether an individual can remain living independently or if they require some level of LTSS or informal care. We decided to measure both ADLs and IADLs to better understand participants' levels of disability,

something which prior studies have not done. We theorized that individuals with higher levels of disability would have more favorable attitudes towards smart home technologies and installing home modifications.

The term "activities of daily living" refers to the basic tasks of everyday life.[136] These activities are deemed to be necessary for independent living at home and/or in the community. Not every organization agrees on the exact definitions of the ADLs, but most organizations agree there are 5 categories which must be met in order to live independently. These categories are as follows:[133,134]

1. Personal hygiene – includes bathing, grooming, and oral care
2. Dressing - the ability to make appropriate clothing decisions and physically dress oneself
3. Eating - the ability to feed oneself, though not necessarily to prepare food
4. Maintaining continence - both the mental and physical ability to use a restroom
5. Transferring - moving oneself from seated to standing and get in and out of bed

The ability of an individual to perform these daily activities, ranging from whether they can perform them un-assisted to if they rely on a caregiver for help, serves as a measure of their independence, and some of these categories (i.e., dressing and transferring) are activities where older adults report falling the most. Within the elderly population, the inability to perform multiple ADLs rises steeply with advancing age, especially for persons aged 85 and over.[137] Individuals who are unable to perform any of these activities are recommended to receive some sort of aid.

Comparatively, "instrumental activities of daily living" are actions that are important to being able to live independently but are not necessarily required on a daily basis.[133] The measures were developed by Lawson and Brody in 1969.[134] The IADLs are more subtle than ADLs, and can help determine the amount of assistance an elderly or disabled person may require. The IADLs include:

1. Basic communication skills - such as using a regular phone, mobile phone, email or the internet
2. Transportation - either by driving oneself, arranging rides or the ability to use public transportation
3. Meal preparation - meal planning, preparation, storage and the ability to safely use kitchen equipment
4. Shopping - the ability to make appropriate food and clothing purchase decisions
5. Housework - doing laundry, cleaning dishes and maintaining a hygienic place of residence
6. Managing medications - taking accurate dosages at the appropriate times, managing re-fills and avoiding conflicts
7. Managing personal finances - operating within a budget, writing checks, paying bills and avoiding scams

An inability to perform two ADLs or three IADLs is one of the eligibility criteria for participation in many statewide assistance programs, and are significant predictors of

mortality.[136] To date, many physicians and adult care social workers use ADLs and IADLs to determine whether or not an individual needs to be placed in long-term care.

*2.2 Qualitative interview questions*

The purpose of the interviews was to explore and better understand the attitudes of older adults towards various home modifications and technology. **Table 2.1** describes the questions which guided each interview.

| **Table 2.1:** Guiding questions |
|---|
| Have you ever had a fall related injury? If so, what happened? |
| Have you changed anything in your environment to prevent further injury? If so, what did you do? |
| Did your children ever approach you about preventing further injury? If so, what did they talk to you about? |
| Have you considered any home modifications or technologies to prevent injury? If so, have you installed any or made any changes? |
| What challenges, if any, do you feel are unique to older adults living in a rural environment? |
| Do you think there is anything I need to know to better understand your experience as an older adult in a rural area? |

Interviewees provided multiple anecdotal stories and examples to illustrate their experiences. Interviewees often answered questions before being specifically asked and discussed the reactions of their children, changes to their environment, and purchases and home modifications added to their home since their fall.

Each of the recordings were reviewed and transcribed using Word. All interviews were transcribed by a single researcher over the course of several weeks in order to ensure patient privacy. Once transcribed, transcripts were checked against audio recordings for accuracy.

*2.3 Data analysis*

Interpretation began during data collection and through the course of the transcription process. Findings from prior interviews were used to identify gaps that required further clarification and exploration during subsequent interviews.

## 3. Results

Many of the interviewees reported living in the community for several decades, having been raised and raising multiple generations of their family within the small county. From observation, attendees of the senior citizen's center are very social, often asking about children and grandchildren. Some interviewees talked about their

relationships with other senior citizen center attendees, as being coaches, teachers, mentors, bosses to other members, other member's children and/or grandchildren. We highlight these observations to bring attention to the social closeness of this community. This strong social cohesion appears to reduce the respondents' perceived need for home modifications/smart technologies, especially for those living in the local retirement communities.

In the town of Mariposa there are two large retirement communities. These communities have various home modifications pre-built into the residences, including ramps, grab bars near the toilets, and railings and seats in the shower. The waiting lists to get into these communities was reported by some interviewees to be long (several months to obtain a space). For those living in these communities, modifications were seen as positive aspects, and one reason that individuals decided to move into these communities.

Furthermore, respondents living in these retirement communities reported the perceived usefulness of various technologies to be low, mainly because the presence of friends and neighbors in these communities acted as a social safety net. For instance, if one member of a social group failed to show up to an event, another would go to knock on their door to check in with them. In the framework of the TAM, this strong community bond reduced the perceived usefulness of technologies such as cameras, Life-Alert and smartwatches, voice-activated devices and lights. Further support for this pattern is the increased interest in technology among residents living outside of these retirement communities.

*3.1 Demographics*

A total of twelve older adults agreed to take part in semi-structured qualitative interviews during a two-week interview period during March and April. Seven female and five males were interviewed; all self-identified as White. The age of the participants ranged between 70-88 years of age, most were or had been married, had multiple children, and all lived independently in their homes. Five of the participants lived-in privately-owned houses, two lived in apartments designed for senior living, and five lived in a mobile retirement community. Only two participants had long term care insurance, and 10 of the 12 participants had experienced some sort of unintentional fall; seven of those 10 required medical attention. All falls were reportedly caused by a sudden loss of balance and carelessness. Two interviewees invested in home modifications or technologies after their fall to prevent further injury. Demographic information can be found in **Table 2.2**.

With respect to independence as determined by the use of the Katz ADL and Lawton IADL questionnaire, the participants could be considered fairly healthy. None reported issues with bathing or grooming, using the toilet, eating, or getting out of bed. Only one reported issues dressing themselves, and four participants reported difficulty when transitioning from sitting to standing or visa-versa (three used walkers or canes). With respect to IADLs, none reported issues with making phone calls, completing housework, managing medications or personal finances; two reported not driving

anymore; one reported not being able to cook for themselves; and seven reported not being comfortable using the internet.

The most common home modification the participants reported having was railings and seats in the shower, grab bars near the toilet, and ramps leading into the home. Technology adoption was rare, with only one participant having installed outdoor and indoor cameras, three having Life-Alert (a wearable device which can call emergency services after being activated) or a smartwatch with similar capabilities, and four having voice activated technologies, including Amazon Alexa or Google home. None of the participants interviewed had any interest in the possibility of owning a self-driving car, and among a majority of participants, opinions were negative.

*3.2 Themes from the interview*

The interview participants spoke about their experiences with technologies and home modifications which fit broadly into five themes: a unwillingness to use technologies because it symbolized a loss of independence, a willingness to use technologies for safety and security, difficulties being in a rural area, and barriers for the adoption of technology.

***Some older adults don't want technology: A symbol of lost independence and ability***

In some cases, the utilization of technology to ease daily tasks was not something interviewees had previously considered. For the more able-bodied older adults, doing chores is seen as a way to get up and get a little exercise. For one 88-year-old, Jacob, chores are his way of staying active.

> *"well I get my exercise vacuuming, and I've thought about one of those robot ones but…. I like doing it myself, at least for the time being."*

But for others, even those who reported discomfort or difficulty while moving or doing chores, technology was not something that they were interested in adopting. Charlotte, aged 70, and living in a mobile retirement community described her situation:

> *"Well I do have a bad back and my knees are bad, bone on bone. I get tired easy cause of my weight, and pain. I just force myself to do it [chores]. But I don't do it as much as I'd like. I have to force myself to do it."*
>
> *Interviewer: "For those instances, would you consider a robotic vacuum to help do those chores for you?"*
>
> *"Probably not, sounds kinda weird, it's something I'd like to take care of myself."*

Charlotte walks slowly with the help of a cane and discussed how her weight problems caused knee pains earlier in the interview. She was vocal in wanting to continue being independent. Here unwillingness to allow a machine to help with her chores may be interpreted as a loss of autonomy and ability.

Betty, a 78-year-old mother of 5 living alone in a senior apartment complex described something similar. To her, the use of technology was not only foreign, but unwanted as long as she is able to perform the task herself.

> *"Well you know, I come from way back, so I don't want to be some old lazy lady letting machines do everything for me. I like getting up and doing things for myself. Although the vacuum sounds mighty good. But I'll do what I can for as long as I can, even though it can get hard at times…."*

However, some participants had other reasons for not considering the use of technology apart from feelings of lost independence and autonomy. Residents in senior apartments or in the mobile retirement community expressed not needing technology because of the presence of neighbors and friends. Abigail, an 80-year-old resident at the mobile retirement community described her attitudes when asked about whether she felt she needed cameras inside her home.

> *well I just I just wouldn't want one yeah, it's like you know, invasion of privacy and I, you know, like I say we got wonderful neighbors and if I needed and I know I know people that sheriffs in Mariposa and you know if I needed somebody way my husband if I needed it if he'd called for me and I'd call for him.*

***Home modification and technologies as a safety measure***

In some instances, home modifications and technologies were installed or purchased before an unintentional fall occurred. For Mark, the presence of technology was able to initiate a swift response by medical professionals when he suffered a fall off his front porch. Although I was able to talk to Mark about his accident, his neighbor, and friend, Alice seemed most impressed with how beneficial his home technology had been in that situation.

> *"He [Mark] took a fall off of his porch and he was really injured pretty badly and hit his car with his body. And it damaged his car. But she [Mark's daughter] was in Sacramento and he had a camera on his porch. And she watched him as he fell, and she looked and she saw him fall off his porch. So she called 911 from Sacramento to call for people to help him in Mariposa. And of course she came from Sacramento but she watched him fall and that's amazing to me. And he has that system so he knows whenever someone is at his home, he finds out and can see it. He knows if a cat tripped it off or a neighbor knocked on his door, you know, it's something, it's amazing, that kind of system is very helpful."*

Upon being asked if she was interested in a camera system like Mark's in case of emergency, Alice responded that she was interested, but since she and her husband had never had a fall or any type of emergency the need for the system wasn't there. When asked how likely she would be to purchase a camera system after an injury in or around her home, Alice was certain she would try to convince her husband that it would be beneficial to have them installed.

For Mark, technology and home modifications were prescribed to him by his daughter, an occupational therapist living in Sacramento. He had various technologies

including indoor and outdoor cameras, automated lights in various locations, and voice activated devices before his fall, all installed and purchased by daughter. After his unintentional fall, he described further modifications done to his property.

> *"After my fall I stayed with my daughter in Sacramento, When I got back she had a ramp installed at the front door with a new metal railing, sturdier than the old one, handlebars in the shower and near the toilet, automatic lights in the rooms, cameras for security, the works…"*

Mark's story was one that many interviewees knew about, and many other interviewees reported interest in purchasing similar technologies for themselves. One of those individuals was Matthew, a retired United States Navy pilot who now walks slowly with the use of a walker and can no longer drive. The following quote by Matthew describes a situation where he could have used something similar.

> *"I fell down there [his driveway] and I really hurt myself and I couldn't get up I kept slipping and I had the hose running and I was filling up this fish tank type water vessel and, and pretty good size and a pretty good flow on the hose and so anyway, pants were soaked, I was, I don't like laying down and I was there for 3 and a half hours in that condition and I finally my wife came up and the in the car from the other house and anyway and helped me up. So I got, you know, anyway so I was okay then but uh boy that was really an ordeal. If I had one of those cameras someone would have got me a lot sooner, I think."*

Although some individuals reported adopting home modifications or technology after experiencing a fall injury, most did not. When asked about whether they moved furniture or made an effort to clear walking spaces, only Mark reported having made those changes. Because all falls were described as "freak" accidents which happened due to a sudden loss of balance, many older adults decided that more careful action was the only thing they needed. Charlotte describes the sentiment of many other interviewees below.

> *Yeah, I'm really more conscious of the last few years, because a few people I know have fallen and end up with broken hips or in the hospital and I don't want that so I'm real conscious about holding onto things, like rails and such. In the house I always take my shoes off, cause they make me feel like I'm gonna fall.*

Of all the participants interviewed almost all of them knew about Mark's fall injury and swift hospitalization due to the camera's he had installed on his property. For this rural community, this well-known instance of how camera technology helped a neighbor in need incited many to start thinking about installing cameras for themselves. For some, Mark's experience highlighted how beneficial camera's and technology could be for older adults living at home alone. For others, technology wasn't something they wanted to install or learn how to use, and they emphasized how they were more conscious and careful while going about their day.

***Technology for other purposes***

For some older adults, investments in technology were done for enjoyment rather than for safety. This was most apparent when it came to voice activated technologies. For adopters of these devices, these older adults talked about their Google Home or Amazon Alexa products. For Abigail and her husband, their Google device is used to look up trivia-based questions they may have while enjoying the television.

*"Yeah it's fun because I always ask what the weather's gonna be today and we check, and and my husband is when we see an old series of some sort he'll "I wonder how old they are now" so I asked Google and she tells yah, so that's neat. [laughs]"*

Apart from the adoption of technology for fun, others reported using voice activated devices for utilitarian purposes, including using their devices for setting reminders, asking about the weather, or getting news. No participant reported using the devices to make phone calls. Mark describes how he uses Amazon devices below.

> *"They're wonderful, set the alarm for such-and-such it's right on the money because I can't trust this guy [gestures to phone] all the time, I also use it for music sometimes, for information, and radio stations. I thought they [were] cute and I gave them out as Christmas presents."*

***Challenges facing rural older adults***

The older adults in this rural environment reported a need to be more independent and less reliant on others. For those living in homes, being on more than 10 acres of personal land wasn't uncommon. Due to their large lot sizes, these individuals have few nearby neighbors and a lot of privacy, something that worries some older adults when they think about the potential of having an injury on their property.

Matthew, who was mentioned earlier, is currently living on 60 acres. Matthew worries about potentially injuring himself and not having anyone to help, especially after his fall in his driveway. Another older adult, a 68-year-old woman named Ester, once lived by herself on a 40-acre lot a few years ago. Following the death of her husband, Ester describes an incident which caused her to rethink her living situation and caused her move from her 40-acre property to a smaller home closer to town for safety reasons.

> *"I took a tumble the dogs took off with me a couple of years ago and drove me down the driveway they saw a deer and, they were live rescues, and they thought "a deer" and they took off and [I] had the leash around my wrist and it almost tore my thumb off [and] turned me around, luckily I didn't hit my head, but I landed on my hip and my upper back and I was pretty scraped up. Luckily the big dog, I had had him a year longer than the little girl, came and he got me. But all I could think of was oh my god did I break a hip? What am I going to do? I'm in the middle my driveway, it's is a tenth of a mile long, there's nobody there six o'clock in the morning what am I going to do…."*

Ester had also previously considered purchasing wearable devices such as Life-Alert for safety purposes. And as of the interview, she hadn't yet invested in the product.

> *"Life-Alert, even my cell phone doesn't work outside because of where I live. So I don't think that the Life-Alert would be a good. I mean, I'm still thinking, I'm still looking into it, but I have to have them guaranteed that it'll be good, that it'll work."*

Ester's lack of reliable service was not unique to her. Margret, a 79-year-old living by herself in a mobile retirement community, described how many of her friends living in various areas around the town would not invest in technologies for safety.

> *"No, we're in a rural area, you just go get it your you do it yourself, we don't have service on every tree here, some places you go you have blind spots where you get no service, so some of this may not work because it if you don't get internet or Wi-Fi or whatever in this certain spot, all the technology you have is not going to help… There's a lot of people that don't have any service, there's many people that don't get it, they get it on the highway and they go two steps down their driveway and they're done. If you're going from Planada, there's a dead zone between Planada and Mariposa, where you don't get any service, even Verizon."*

In this rural community large lot sizes and long distance from neighbors means little to no visibility from the road. For individuals living on private property the fear of experiencing an accident and not being able to call for help is greatly concerning. For rural dwelling individuals living in the community, emergency response technologies like Life-Alert aren't always a viable option due to poor or no connection.

### *Barriers to adoption of modifications and technology*

The enthusiasm and interest in home modifications and technologies was often undercut by other factors not wholly unique to rural living. The participants often brought up barriers, including: cost, concerns about their ability to learn and memorize commands, privacy, and a lack of information about products. For one interviewee, Luke, a 79-year-old adjusting to living on his own since the passing of his wife, describes how cost keeps him from adopting the wearable device Life-Alert.

> *"Well they always cost a lot more than what you think [in regards to Life-Alert] and I sent for of those things you know. And then all a sudden in two months here comes three months then it costs about twice as much as what is was supposed to be. And this is not long after my wife died, you know where everything happened, and I said forget it.."*

Another participant, Mark, described previously, also decided against purchasing Life-Alert due to cost, however, because he regularly carries a smartphone with a data plan, he and his daughter decided to invest in a smartwatch which connects with his phone. This way, Mark can use the emergency call feature of his watch to reach emergency services in much the same way Life-Alert would in the same situation.

*"We were thinking about having something to wear in case you fall type thing, we thought about Life-Alert but then we found out it was cheaper to have the watch than to do the other service, and Verizon will do it for you so it's cheaper. the watch is like 300 bucks which is cheap, because I don't know what the other thing [Life-Alert] cost but then you got $30 a month, $30 a month for monitoring. This one here you just activate when you fall which is better."*

It was not uncommon to see interviewees with smartphones. Although they were not asked about their phone directly, many carried it in their pockets and placed them on the table along with their wallets or purses, and other personal affects, as they sat.

Apart from the cost of investing in technologies, some older adults worried that they wouldn't be able to remember how to control these new devices. Margret is one of these older adults, and thinks that home modifications and technology are very helpful, but is hesitant to adopt them for herself.

*"I think it's fascinating I think it's wonderful and I'm totally amazed because my grandkids can all do all this, seven great grandkids can do all this stuff but I don't have the patience to sit down and learn it I can go take a computer class I can be the top of the class in the classroom walk out the door it's still in the classroom I don't retain the information"*

Another barrier for older adults looking to adopt new technologies is trust. Many older adults interviewed described not being comfortable trusting large companies or the government, to keep their data private. This was most clearly stated by Lukeord, who found technology to be interesting but was unwilling to adopt any technology which would be placed in his home.

*"I would think all of it would be like spying, just like TVs now there you can sit there and the government could watch you at all that through these things"*

Interviewer: "S*o earlier you did say that you would be interested in camera for outdoors?"*

*"Yes"*

Interviewer: "*Would you ever put them inside?"*

*"I don't think so, you don't know who's watching the damn thing and nowadays they can almost watch you to the TV and record and all that kind of stuff. No and all kinds of reasons not to."*

The last barrier to adoption among this population was knowing that the products and technologies existed. John, a wheelchair bound 82-year-old, was extremely enthusiastic about all the technologies talked about during the interview, but he didn't know that they existed previously and wanted more information.

*"I like new technology, I have elderly neighbors of course, it's an elderly apartment complex you know, for the elderly, and so my lady friend she doesn't care for computer stuff like that. but yeah I think technology is great and is*

*helping people everywhere. People at home, people like me ordering supplies or whatever, I wish I knew more."*

This sentiment was echoed by Matthew, who also expressed being interested in technology, but didn't know where to start or where to turn to for more information.

*"I'm comfortable with it but I don't know what the next step is, so you know other devices in other words, but then also the cost if, yeah and but I'd be very interested in seeing what else is available, I think the biggest weakness of the companies that are making these devices is that they don't advertise very well, they're not coming out to senior centers like this, If you're out and if you're not regularly keeping up with the Internet then there's no way of you knowing what kind of things that you can do to keep yourself safe."*

The older adults interviewed reported being hesitant to adopt technologies due to cost, ability to learn and memorize commands, concerns about privacy, and a lack of information. However, many of them reported having children and grandchildren immersed in technology, and internet-based devices, something that none of the interviewees were opposed to. When asked about whether they had anything else they wanted to tell the interviewer, Margret talked about the idea of older adults needing to acclimate and adjust to technology before adopting and purchasing them for themselves.

*I think what I'm saying [is] once they adjust to them [technology] they would be fine, and I think the earlier people realize they need these things the better because after a while they're just so used to using them then then they don't get startled or they don't get shook up… so I think early on, if they would get it before they absolutely have to have it, [it] would be more beneficial to them only because they would be able to adjust to having it and knowing what it does for them. Because the elderly forget things in the immediate memory bank but they have a longer term memory so that's why I think that would be beneficial for them.*

## 4. Discussion

The themes which emerged from these interviews highlight a general interest in modifications and technology while underscoring the difficulties and some unique benefits which older adults living in this rural area face.

With regards to voice-activated devices and technology designed to help with chores, preferences among the older adults sampled was mixed; some older adults liked the idea of adopting these various technologies, while others were against the idea, preferring to complete their chores and go about their lives without aid. Despite previous research suggesting that technophobia could be a reason for not adopting these devices, interviewees seemed most concerned with the quality of the work done by these devices.[127,128] Distrust in the technology and concerns about privacy were cited among the participants who vocalized not wanting to adopt. Consistent with previous research, among the older adults open to adopting technologies, concerns about their ability to

learn and memorize commands, low self-efficacy, acted as one barrier to adoption.[129,130] However, with the increasing number of elderly individuals being technologically adept, the prevalence of barriers, like low self-efficacy and technological anxiety, are likely to diminish with time. Additionally, other factors including cost, concerns about privacy, and a lack of information act as barriers for interviewees from adopting technologies they self-described as helpful, which is also consistent with prior research.[52–55] In the framework of the TAM, among the older adults who reported adopting voice-activated devices, their decision was based on convenience or novelty rather than for perceived usefulness or ease of use.

Consistent with prior research, the installation of home modifications was a reactive response to suffering injury.[53,65] Among the participants living in homes with large lot sizes, the installation of rails was most common, followed by grab bars and seats in the bath and shower. These older adults shared common worries about accidents on their property, and many were considering downsizing and moving to a more populated area (closer to the town). Others mentioned planning to apply for placement in a local retirement community or planning on moving in with their children. For those who did not want to move, the idea of installing or purchasing technologies such as cameras and smart watches (given they got signal) was perceived positively.

The various services provided by the senior citizens center, especially the transportation services, are especially helpful to older adults residing in this rural community. Because Mariposa is located in a medically underserved area, the presence of a free bus service to two larger cities which pick up individuals at their home and take them directly to their appointments is invaluable.[96] Furthermore, services including meal delivery (also provided by the senior citizens center) helps address IADLs, which are considered vital to independent living.[133] Unfortunately, we were unable to find previous research or information regarding the prevalence of similar programs among rural communities across the United States. Future research may want to examine whether programs like the ones found in Mariposa exist in other rural communities; if so, the perceived usefulness and need for technology may be considered low in these locations as well.

Being close with relatives, children and grandchildren, influenced whether interviewees were willing to adopt technologies. For some, their children or grandchildren were able to convince the older adult that home modifications and technology were necessary for safety. However, among the interview participants, most did not have children who approached them about home modifications or technology, and upon asking, none expect their children to make inquiries into their safety. Despite this, interview participants had various plans for when they were unable to care for themselves including moving into the local retirement communities, moving closer to town, or moving in with their children or relatives.

Additional research should be conducted to better understand how the relationship between parent and adult child, as well as the feelings of the adult child towards home safety technology, affects the adult child's decision to suggest these technologies to their parents. Additionally, future research should focus on the views of minority populations

towards technology, a population which previous research has described as being less likely to adopt technology and more likely to move in with their children in advanced age.[55]

## 5. Conclusion

Results from this study indicate that older adults living in this rural environment are not opposed to adopting home modifications and technology if they feel they need it. However, the high levels of social cohesion for those living in dedicated retirement communities decreases the perceived usefulness of many safety technologies perceived as being more useful among individuals living on their own private properties. Being in an isolated, rural environment comes with various barriers including cost, ability to learn and memorize commands, privacy, and a lack of information. These barriers may not be unique to older adults living in rural communities, but special attention and time may be required to reach these populations if getting them to adopt these technologies is the goal. Programs, both government- or private sector-driven, which are concerned about increasing the adoption of these technologies among rural populations should focus their efforts among older adults not living in dedicated retirement communities.

Future research should examine the attitudes and preferences of the children of older adults towards their parents' safety. Questions remain as to whether the children of some older adults think about their parent's safety, whether the act of a child asking their parent about adopting home modifications or safety technologies modified by physical distance or how connected the parent and children are, and more. For a population located in an isolated and rural environment, home modifications and technologies have the potential to increase safety and security.

## Study 3: Preferences in home modifications and technologies among family members of older adults: A discrete choice experiment

### 1. Background

"Aging in place" is a commonly used term defined as "the ability to live in one's own home and community safely, independently, and comfortably, regardless of age, income, or ability level".[115] It is widely accepted that older adults prefer to "age in place", because it enables them to maintain independence, autonomy, and connections to social support, including friends and family.[116–118] Having people remain in their homes and communities for as long as possible helps avoid other costly living arrangements, including institutional care, and is favored by policy makers, health providers, and older adults.[119]

As older adults age, their risk of various injuries in the home -- most commonly fall-related injuries -- increases. In the USA, approximately one-third of all elderly adults experience a fall annually.[25] The United States Centers for Disease Control and Prevention estimated the cost of treating fall injuries among older adults was $34 billion dollars in 2013 and will rise to $67.7 billion dollars by 2020.[1] There are a variety of factors which can increase the risk of fall, including balance, gait, and a host of biological and environmental factors.[26,68,75,76,138–140] Reports also indicate that older females are more likely than older males to have serious fall injuries.[141] With the growing proportion of older adults increasing yearly, it will be imperative to find cost effective ways to prevent fall-related injury. Prior studies indicate the most effective ways to reduce the risk of fall-related injuries among community-dwelling older adults (those currently aging in place) include participation in exercise programs along with the installation of home modifications.[40–44]

For older adults hoping to age in place and remain independent, previous research indicates that the installation of home modifications reduces the risk of serious injury.[48–51] Various products are currently marketed and sold to older adults to help them accomplish tasks which have been deemed necessary to being able to live independently. These tasks are commonly referred to as "activities of daily living" (ADL) and "instrumental activities of daily living" (IADL).[133] Tasks included in the ADL and IADL indices include the ability to transfer from sitting to standing position, prepare meals, travel, complete housework, etc. An example of a product that can help a person who has difficulty moving from a standing to a sitting position would be a railing or grab bar which would help them raise or lower themselves. In addition to these home modifications, the AARP (formerly the American Association for Retired Persons) and private companies have begun to recommend new electronic devices marketed as helping to address other ADL and IADL needs, including indoor and outdoor cameras, wearable smart-watches, communication products, etc. [120,121] However, a majority of these products have not been scientifically proven to have any beneficial impact on the ability of older adults to complete ADLs and IADLs.

*1.1 Factors Valued by Older Adults in Home Modifications/Smart Home Technologies*

Various qualitative studies have been conducted in order to help elucidate the decision-making process of older adults and their families as they decide to modify their homes to better allow them to age in place. Among the studies conducted, the five main attributes reported to be important to older adults thinking about modifying or installing devices in their home include: security, safety, ability to communicate and remain social, privacy, and cost.[52–55] Research has been focused on addressing each of these factors, and various new technology products are also being marketed as being able to increase levels of security, safety, and communication, potentially at the expense of privacy.

*Security* can refer to being free from danger or threat, and in reference to the home is defined as the ability of the home to keep intruders out. Studies indicate that older adults value home modifications and installations that increase their security.[52,53] Between 2003 and 2013 there were nearly 1.8 million instances of property crimes (burglary, motor vehicle theft, and robbery) among adults aged 65 and older.[142] Despite being at lower risk of experiencing property crime compared to younger adults, older adults are more concerned about being a victim of property crime compared to their younger peers.[143] Research has found that experiencing property crime is associated with high levels of depression and anxiety.[142,143] To increase security and decrease the risk of property crime, Americans spent $28.4 billion in 2014 on cameras, alarm systems, and security networks, a figure expected to exceed $45 billion per year by 2020.[144]

*Safety* refers to the chance of unintentional falls that can lead to injury. A survey of 296 homes belonging to older adults found that the homes contained an average of 13 hazards that could lead to falls.[54] The installation of home modifications such as hand rails, ramps, and increased lighting, as well as environmental changes such as removing rugs and other tripping hazards, have been demonstrated to reduce injury.[48–51] Safety can also refer to the ability to get assistance after an unintentional fall occurs. Wearable devices, also known as medical alert devices, including LifeAlert, and more recently Apple, Google and Samsung watches, can make emergency calls with a single touch in the event a person is unable to reach a phone to call for help. Despite a large increase in the number of older adults who own these wearable devices, there is no information regarding how often they are used to actually contact emergency services, or how the devices' ease of use and utility are perceived by older adults and their families.

For older adults looking to age in place, the *ability to communicate and socialize* with friends and family is important. Prior research indicates that isolation due to the inability to travel or declining ability to move around is associated with mental health conditions including depression and anxiety, as well as declines in physical health.[145] With the ability of technologies that connect people via the Internet using video-conferencing, messaging, and talking, devices such as tablets, computers, laptops, and smartphones may be able to increase an older adult's ability to stay connected with their friends, family, and community.

*Privacy* has also been a concern for older adults looking to modify their homes for the purpose of aging in place. While technologies such as cameras, computers, tablets, and other devices can help increase safety, security, and communication, research suggests that there is an aversion to relying on them due to concerns for online and

personal privacy.[118] For many people, the idea of being monitored in their home is negative enough to outweigh the potential benefit of increased safety, especially when considering devices that record their voice or movements.[55]

The *cost* of installing home modifications and smart home technologies is also a concern for older adults. Nearly one in ten (9.3%) of older adults live in poverty in the United States, but among those living alone, the proportion is nearly twice as high, at 17.3%.[146] Costs for home modifications can easily exceed $2,000 depending on what needs to be installed, and without subsidization, home modification for the purpose of aging in place may be out of reach for many older adults.[52]

*1.2 Consulting Other Family Members*

Although the preferences and feelings of older adults towards various home modifications and smart home technologies are important to consider and study, it is also important to consider the preferences of their children or other relatives. Many older adults receive informal care from family members; in 2009, more than 60 million family caregivers were providing unpaid care to older adults, at an estimated cost of $450 billion.[16] National estimates report that 40% of informal caregivers report high burden, meaning they spent more than 20 hours a week providing care to their older adult relatives.[17] Due to the impact on family members' time and finances, it is important to consider the role of the family member when older adults make decisions about aging in place.[53] Currently, there are no studies which exclusively examine the preferences of family members of older adults regarding home modification and smart home technologies.

Existing research assessing the preferences of family members towards home modifications for their older relatives did not explore their preferences compared to the preferences of their older relatives.[53] In this qualitative study, of the 19 family members of older adults who were interviewed, there was no section which examined their preferences and experience with home modification projects separate from their older adult family members. Other research has reported that social factors, including opinions of family members and the closeness of relatives, affects older adults' decisions about whether to age in place, modify their homes, or move elsewhere.[147] However, this review did not identify any study examining how much of an influence these family-specific social factors had on the decisions of older adults. It mentioned only that older adults considered the opinions of their family members, along with a number of other factors, while making their decision.

*1.3 Aims*

This paper aims to understand how the adult children of older adults evaluate the importance of five attributes (security, safety, communication, invasiveness, and cost) that prior research has suggested are integral to decisions around home modifications and technology adoption. This study utilizes a survey questionnaire and a discrete choice experiment (DCE) to better understand which attributes are most important to these adult children.

A DCE is a quantitative method used to understand preferences from respondents without directly asking them to state their preferred options. In a DCE respondents are presented with a series of alternative hypothetical scenarios containing a number of variables or "attributes", each of which may have a number of values or "levels". Utilizing a DCE allows researchers to understand what combination of attributes and levels are most desired by respondents.

## 2. Methodology

### *2.1 Participant Recruitment and Survey Design*

Respondents were recruited and screened by a survey company (Qualtrics). Respondents were required to live within California and to have at least one relative over the age of 70 years currently living alone. Respondents were compensated $8.00 for their time.

At the start of the survey, respondents were asked to identify any grandparents, parents, aunts and uncles, and siblings older than 70 years and currently living at home by themselves. For respondents with more than one relative fitting this description, one was chosen at random and respondents were asked to answer all further survey questions with this relative in mind. Respondents were asked a number of demographic questions about that relative, including their age, need for walkers or wheelchairs, and ability to use devices such as computers, tablets, smartphones, and the internet.

Respondents were then provided with a general description of different home modifications and smart home technologies that are marketed as increasing security, safety, and communication. Respondents were also provided with descriptions of home technologies' different levels of invasiveness and cost (see section 2.3). Following this introduction to the attributes (security, safety, communication ability, invasiveness, and cost), their levels, and the various products included in those levels, respondents were randomly assigned to one of ten versions of the discrete choice experiment.

The last part of the survey gathered demographic characteristics of the participant. These demographic characteristics included participant's age, race, sex, education level, income, and marital status. Respondents were also asked to rate the levels of security, fall safety, communication, and privacy in their own home as well as in the home of their older adult relative. IRB approval for this project was obtained from the University of California, Merced.

### *2.2 Discrete choice experiment*

This discrete choice experiment was designed to simulate the decision-making process among adult respondents being asked to choose between different "home technology packages" that would offer varying levels of security, safety, communication ability, and invasiveness, at varying costs, for an older adult relative currently living at home by themselves. Each of the 10 versions of the discrete choice experiment had 16 choice sets; respondents were asked to complete all 16 sets. An example of a choice set

can be seen in **Figure 3.1**. Respondents were asked to make their choices in the context of being the primary decision maker for their relative looking to improve their relative's living situation, and to express their preference for each question presented.

Each choice set had three options to choose between. Two of the three options had the participant's older relative age in place, while the third option specified that no home technology package would be adopted and that the relative would, instead, move in with the participant. For the two options that had the relative age in place, randomized variations of the levels for each of the five attributes was presented. For the third option (having the relative move in with the participant), only cost was randomized; for this option, levels of the other four attributes were inferred during the analysis phase from respondents' subsequent ratings of the security, safety, communication ability, and invasiveness of the technologies currently in their own home.

*2.3 Identifying attributes and levels*

The attributes and levels for this discrete choice experiment were based upon a literature review of factors previously identified as important in the decision-making process regarding home modification among older adults.[52–55] The list of specific home modifications and smart home technologies included in the levels of each attribute was informed by qualitative interviews with older adults conducted in an earlier phase of this project.

A total of five attributes were selected for this experiment: four attributes (security, safety, communication, and invasiveness) with three levels (high, medium, and low), and one attribute (cost) with six levels. Attribute levels are influenced by the overall number of home modifications/technologies (except invasiveness and cost). Higher levels of security, safety, and communication refer to having more modifications and products in that category. The low level includes one or fewer modifications/technologies, the medium level includes two to three modifications/technologies, and the high level includes four to five modifications/technology.

For invasiveness, the three levels refer to variation in ability to know what a person is doing in their home at any given time. A low level of invasiveness is defined by high privacy and an inability to monitor a person's activities in their home, while high invasiveness is defined by low privacy and the ability to monitor the activities of a person in their home at any given time.

Cost was defined as the amount of money respondents would be required to pay out of pocket to implement the choice they preferred. This attribute's six levels were categorized as $0 (i.e., costing the participant nothing), $1,000, $5,000, $10,000, $20,000 and $50,000. Respondents were told to consider the cost as a one-time payment.

**Table 3.1** presents the attributes, levels, and a description of the modifications and technologies included in each level.

*2.4 Statistical analysis*

Within the discrete choice experiment framework, it is assumed that if choice 1 is preferred to choices 2 and 3, then the utility benefit derived from choosing choice 1 will be greater than both choices 2 and 3, given the set of attributes and levels of each choice.

For the third choice -- having the relative move in with the participant -- four attributes (security, safety, communication, and level of invasiveness) were retroactively filled in using questions which asked respondents to rate these attributes for their own home.

A conditional, fixed-effect, logit model was used to account for the fact individuals answered several multiple-choice questions (i.e., choices were nested within individuals). Because there are three choices for respondents to choose from, the choice selected was coded as 1, and the other two were coded as 0, in accordance with methods found elsewhere.[148] The participant's choice of preferred home package (choice 1, 2 or 3) was the dependent variable. The main effects model included security, safety, communication, invasiveness, and linearized cost as the dependent variables. For all analysis, significance was set at a p-value of less than 0.01.

In addition to utilizing the conditional, fixed-effect, logit model to calculate beta coefficients, willingness to pay (WTP) was also calculated. In order to calculate WTP, cost was added to the model as a linear variable. WTP was calculated by dividing the value of the beta coefficients of security, safety, communication, and invasiveness, by the beta coefficient of linearized cost. By comparing the WTP values, respondent preferences for the factors can be analyzed. A single model which included cost as a categorical variable was run to verify assumptions related to calculating willingness to pay. Specifically, that as cost increases, demand (or the selection of that home package) should decrease.

In addition to analyzing the main effects (the 5 main attributes), I hypothesized that two other factors would influence the preferences of respondents regarding home technology packages. These two factors are (1) the gender of the older relative, and (2) the relationship between the older adult and the respondent. These two factors were chosen because (1) prior research indicates that females fall at higher rates than males;[141] and (2) respondents may have different preferences in home packages depending their relationship with that older adult. For the stratification of relationship of the older adult to the respondent, I created 4 groups: grandparents, parents, aunts and uncles, and siblings.

I hypothesized that respondents would choose packages with higher levels of safety for female relatives compared to males, and that respondents choose packages with higher levels of safety for grandparents and parents compared to those chosen for aunts, uncles, and siblings. In addition to the stratified analysis, we entered the two control variables into the model by interacting them with the main effects.

Data were managed and analyzed using STATA 14.

## 3. Results

A total of 250 surveys were completed by respondents, all living in the state of California. 61% of respondents were female, 78% were White, 6% Black, 5.6% Hispanic, 8.8% Asian, and 1.6% other race. Compared to the state of California, which is 36.8% White, 39.3% Hispanic, 6.5% Black, and 15.3% Asian, our sample is not ethnically representative.[149] Respondents averaged 60.7 years of age and were well educated on average, with 57.6% having finished college, 33.2% having completed some college, and 9.2% having finished high school. Comparatively, the US Census Bureau reports that 32.6% of Californians over the age of 25 have completed college as of 2017, indicating that our sample was more educated that the general population of California.[149] 58% of respondents were married, 15.6% were single/never married, and 26.4% were divorced, widowed, or separated. Complete demographic information for the respondents can be found in **Table 3.2.**

Among the respondents, 16.8% had grandparents living alone, 49.2% had parents living alone, 11.6% had aunts or uncles living alone, and 22.4% had older siblings living alone. The average age of the older relatives was 81.5 years. Respondents reported that a majority of their older adult relatives living alone were female (76.0%). Respondents also reported that 56.4% of their older relatives were moderately to highly proficient with computers, 56.8% were moderately to highly proficient with smartphones, 46.0% were moderately to highly proficient with tablet devices, and 53.2% were moderately to highly proficient using the Internet. Respondents reported their older adult relatives as being very mobile, with 74.0% not needing a walker and 89.2% not needing a wheelchair. Complete demographic information for older adults can be found in **Table 3.3**.

Respondents rated the security of their own homes to be higher than that of their older adult relative, with 73.2% being moderately or highly secure, compared to 24.8% among their older adult relatives. Respondents also rated their own homes as being safer (73.2% moderately or highly safe) compared to the homes of their older adult relative (52.4% moderately or highly safe). The level of communication in the respondent's home was similar compared to the homes of their older adult relative (86.8% compared to 89.6% for moderate to high communication ability). Full results of the comparison between respondents' homes and the homes of their older adult relatives can be found in **Figure 3.2.**

Respondents were confident that their older adult relative could care for themselves independently (91.9% reported medium to high confidence), but 50.8% worried about an unintentional fall happening to their relative. A majority of respondents (53.2%) lived within 1 hour of their older adult relative, and 32.8% lived more than 3 hours away. 11.6% of respondents provided care for their older adult relative, and another 26.4% had a different family member providing care for that relative. Nearly 40% of all respondents described themselves as being the primary decision maker for their older adult relative. If their older adult relative had to move in with them, respondents were confident that they could meet a variety of their needs (ADL and IADL tasks) including helping their relative eat, bathe, dress, take medications, manage finances and more. Nearly 50% of respondents reported feeling comfortable coordinating medications and

medical care for their older adult relative. For all other tasks, respondents reported confidence ranging from 66.0% through 84.4%. Full results can be found in **Table 3.4**.

*3.1 Conditional Logistic Analysis: Main effects model*

The conditional logistic regression analysis indicated that when choosing a home package for their older adult relatives to help them age in place, respondents valued higher levels of security, safety, and communication, and lower levels of cost and privacy. In the model with linearized cost, respondents preferred medium (β coefficient: 0.19; SE:0.05) and high (β coefficient: 0.20; SE:0.05) levels of security over low levels of security. Higher levels of safety were also important to respondents, with respondents preferring home packages with medium (β coefficient: 0.15; SE:0.05) and high safety (β coefficient: 0.24; SE:0.05) compared to those with low safety. Respondents favored medium levels of communication (β coefficient: 0.22; SE:0.05) but not high levels of communication (β coefficient: -0.03; SE:0.05). Respondents preferred home packages with medium (β coefficient: 0.15; SE:0.05) and high (β coefficient: 0.42; SE:0.05) levels of invasiveness, compared to home packages that offered complete privacy. Regarding the model which included cost as a categorical variable, it is clear that lower cost was valued by respondents, with each increase in cost being associated with a significant decrease value of the β coefficients.

Willingness to pay estimates indicated that medium and high levels of security are valued similarly, with high security being slightly more valued (high WTP= $4,750.45 compared to medium WTP= $4,597.22). High levels of safety are valued more than medium levels of safety (high-safety WTP= $5,757.18 compared to medium-safety WTP= $3,585.26). Medium levels of communication are valued significantly more than high levels of communication (medium WTP= $5,294.17 compared to high WTP= -$810.55). Lastly, high levels of invasiveness were valued higher than medium levels of invasiveness (high WTP= $10,248.10 compared to medium WTP= $3,544.25). Full results from the main effects model can be found in **Table 3.5.**

*3.2 Stratified Analysis: Older Relative's Sex*

When stratified by the gender of the older adult respondent, some noticeable changes in association were observed. My hypothesis that respondents with female older relatives, living alone in the community, would prefer higher levels of security and safety was not supported. Respondents valued higher levels of security for older adult males (medium β coefficient: 0.03; SE:0.10; high β coefficient: 0.15; SE:0.05) compared to females, whose p-values for medium and high security were insignificant. For male relatives, using WTP estimates, respondents valued high security packages 4.9 times higher than medium security packages. Respondents also valued high safety for male relatives (β coefficient: 0.06; SE:0.11), but respondents who identified their relative as being female did not value higher levels of safety to a statistically significant degree. Using the WTP estimates, respondents value safety to a lesser degree compared to security for male relatives. Respondents valued home package with medium communication ability compared to packages with low communication ability for male relatives (medium communication β coefficient: 0.21; SE:0.11), coefficients for female

relatives remained insignificant. Results indicate that respondents valued packages with high levels of invasiveness for both female (β coefficient: 0.41; SE:0.11) and male relatives (β coefficient: 0.48; SE:0.11). WTP estimates also indicate that invasiveness is the most important factor respondents consider when choosing home packages for both males and females, with WTP value for high levels of invasiveness being more than double the next closest significant estimate (medium communication for males). Results from these gender-stratified models can be found in **Table 3.6**.

*3.3 Stratified Analysis: Relationship Between Older Adult and Respondent*

After stratifying the analysis by the relationship between the older adult with the respondent, subtle variations in preferences towards to attributes between the groups were observed. Across all types of relationships, home packages with lower costs were preferred over packages with higher costs. Results from this stratified model can be found in **Table 3.7**.

The analysis indicated that when considering home packages for a grandparent, no estimate among this sub-group was statistically significant. However, there was a trend for respondents to prefer packages with high levels of security for their grandparents (high security β coefficient: 0.23; SE:0.12).

When considering home packages for a parent, results indicated that higher levels of security, safety, communication, and invasiveness are valued. Respondents preferred packages with high levels of security (β coefficient: 0.24; SE:0.07), high safety (β coefficient: 0.34; SE:0.08), and a medium level of communication (β coefficient: 0.29; SE:0.08). Respondents also preferred packages with a high level of invasiveness (β coefficient: 0.56; SE:0.07) compared to packages with low invasiveness. WTP estimates indicated that high levels of invasiveness were the most valued attribute of the home package for parents ($13,379.62), while other attributes – high level of safety ($8,167.16), medium level of communication ($6,961.37), and high level of security ($5,749.05) – were also valued to a significant degree.

When considering their aunts and uncles, respondents did not significantly prefer packages which increased security, safety, communication, or invasiveness. Despite being statistically insignificant, respondents tended towards higher levels for each of these attributes.

Lastly, when considering home packages for their siblings, respondents valued higher levels of safety, communication, and invasiveness. Respondents preferred packages with a medium level of security (medium security β coefficient: 0.26; SE:0.11) over packages with low security. Respondents preferred packages with medium and high levels of safety (medium safety β coefficient: 0.39; SE:0.11; high safety β coefficient: 0.36; SE:0.11) over packages with low levels. Respondents also preferred a medium level of communication (β coefficient: 0.51; SE:0.12) over low levels of communication, and were uninterested in high levels of communication. Respondents also preferred home packages with a high level of invasiveness (β coefficient: 0.44; SE:0.11) compared to packages with a low level of invasiveness. For this group, WTP estimates indicated that communication was the most valued attribute (medium communication WTP=

$12,236.61), with high invasiveness being the second most valued attribute (high invasiveness WTP= $10,612.45). Following those two attributes, medium and high safety (medium WTP= $9,468.35; high WTP= $8,657.53) and medium security ($6,291.54) were also significantly valued.

Because respondent preferences towards the attributes of security, safety, communication, and invasiveness differed depending on the relationship of the older adult to the respondent, my hypothesis was supported. Lower cost was the only attribute which all respondents valued for each stratified group. Regarding grandparents, respondents were only concerned about safety. When thinking about attributes home packages for parents, respondents preferred higher levels of security, safety, communication, and invasiveness. For aunts and uncles, only lower costs influenced respondents. And regarding their siblings, higher levels of safety, communication, invasiveness were preferred by respondents.

### *3.4 Interaction models*

When attempting to include the gender of the older adult relative and the annual income level of the respondent by interacting these terms by the main effects, we found that the model did not converge, likely because our sample size was relatively small.

## 4. Discussion

### *4.1 Implications from the conditional (fixed-effects) model*

This discrete choice experiment assessed the preferences of family members of older adults towards home packages with varying levels of attributes, including security, safety, communication, invasiveness, and cost. Based on the analysis, respondents valued security, safety, and communication over the privacy of their older relative. Respondents preferred home packages with higher levels of invasiveness. Multiple studies report that decreases in privacy, caused in part by the adoption of technologies such as cameras and voice-activated systems, are a concern for older adults.[55] However, these results indicate that the relatives of older adults value the ability to monitor their relatives. With older adults wanting to age in place independently and privately, and their relatives desiring higher levels of invasiveness, families will have to negotiate a balance between security, safety, independence, and invasiveness. Future studies should examine which products older adults and their family members purchase, and how they perceive any trade-off between the security, safety, and communication of those technologies with their cost and invasiveness.

In line with previous studies, we found that lower-cost choices were valued over those with higher costs. The cost of retrofitting a home to enable an older adult to age in place safely will vary from family to family, dictated by the needs of the older adult and the size of their home. However, previous studies indicate that many families have trouble affording home modifications for their homes.[52] As companies like Apple

continue to seek FDA approval for new health-related devices and technologies, government entities will need to consider whether to subsidize the costs for consumers who may benefit from them. Future research should evaluate the effectiveness of the devices and technologies being developed and purchased, as well as determine if it is cost-effective for consumers and government entities to invest in these products.

Results also suggest that respondents valued home packages that offered their older relatives moderate, but not high levels, of communication and socialization. As prior research reports that social isolation is associated with depression and anxiety, it is understandable that relatives of these older adults would want to keep them connected to their social groups.[145] The pew research center reports that in 2016, 51% of adults over the age of 65 had home internet access, while being a modest 3% increase since the previous measurement in 2013, it is expected that adoption will not slow down, and that a growing number of older adults will be able to connect and communicate efficiently with friends and family over the internet.[150] To date, a majority of literature surrounding the increased rate of technology adoption in older adults is concerned with increasing their access to healthcare and health information, as well as increasing their cognitive function. However, as devices such as smart-watches and tablets, along with compatible software applications, continue to be developed and their adoption more widespread, research will need to determine if online interaction and socialization is as beneficial as in-person interactions.

Regarding the stratified analysis, respondents were more likely to choose packages with higher levels of security and safety for older males, but not for older females. It is well documented that females tend live longer lives, and have fewer chronic conditions, compared to their male counterparts.[151] Because of this, I my initial hypothesis was supported, there were statistically significant differences in preferences towards home packages dependent on the gender of the older adult relative. Respondents may feel their male relatives required more security and safety compared to their female relatives. To better understand why this discrepancy exists, future studies should ask respondents to list chronic conditions their relatives have, or rate them on validated measures of independence such as the activities of daily living.

Regarding the relation of the older adult to the respondent, preferences of respondents towards home packages were always influenced by cost. This stratified analysis also demonstrates that respondents desire higher levels of each attribute when considering the living situation of immediate family members (parents and siblings) but did not prefer higher levels of the attributes when considering the living situations of extended family members (grandparents and aunts/uncles). These results imply that if the preferences of family members are taken into consideration during the decision-making process of modifying the home of an older adult, the children and siblings of that older adult will likely desire higher levels of security, safety, communication, and invasiveness.

*4.2 Findings from the general survey*

Survey respondents were very confident in their ability to care for their older adult relative if needed. Respondents were least confident in their ability to help manage

medications and medical care for their older relative, with just under half of respondents indicating that they would be confident in providing that care. However, for all other tasks (assisting in feeding, bathing, dressing, and managing issues including emotions, finances, transportation, etc.), between 66.0% and 84.4% of respondents felt they could manage assisting their older adult relative. This finding indicates that relatives of older adults may be see themselves as able to care for their loved ones if needed. However, previous national reports indicate that, depending on the level of care required by an older adult, caregivers may spend upwards of 20 hours a week caring for their loved ones.[17] These results may indicate that respondents over-estimate their ability to care for their older relatives.

Respondents rated the homes of their older adult relatives to be significantly less secure and safe as compared to their own homes, with 75.6% of respondents rating the security of their older adult relatives' home as low. Increasing security by adding better locks, cameras, and lights may help increase the perceived security of the residence. Results from the regression model also indicate that respondents had higher odds of selecting options with greater levels of security. Previous research has reported that older adults are more concerned about the security of their homes compared to younger adults.[143] However, reports indicate that approximately 32.5% of adults aged 65 and older have an alarm system or safety lights installed in their home, which is not significantly higher than their peers, 28.4% of adults aged 30-44 year and 32.4% of adults aged 45 to 64 years also reported having alarm systems or security lights as well.[152] This discrepancy in security rating could potentially be due to respondents believing that their older relatives live in more dangerous places, or are unable to protect their homes. With the Federal Bureau of Investigation reporting that property crime in 2018, and estimates for early 2019, are continually decreasing within the United States, their ratings of home safety may simply be based on their personal perceptions and feelings rather than the objective safety of their relative's residence or neighborhood.[153]

Nearly half (47.6%) of respondents rated the safety of their older relatives' home to be low. However, the safety of their older adult relative was a main concern for respondents, with home packages offering higher levels of safety being more valued over those offering low levels of safety. Previous research conducted in the north-eastern region of the United States indicates that the homes of older adults average of 13 hazards in the environment which could lead to falls.[54] Because this survey did not ask why respondents assigned these ratings to the homes of their older relatives, further research may want to assess whether older adults are living in homes which are objectively less safe compared to the homes of younger adults.

Of the 4000 choice sets respondents completed, the choice of having the older relative move in with the respondent was selected 19.5% of the time. Of the 250 respondents, 34 (13.6%) of them selected this choice in more than half of the choice sets. These results indicate that there is a subset of younger family members who prefer that their older relative move in with them rather than have that relative continue to age in place. Due to limitations of the survey, it is impossible to know whether these families have already planned an eventual re-location of their older relatives to a younger family

member's home. Future studies should attempt to understand what proportion of older adults plan to move in with younger relatives, and whether products which promote aging in place affect their plans, if at all.

### *4.3 Limitations*

Limitations of this study include the discrete choice attributes not being fully independent from each other. For instance, in home packages with high security we asked respondents to consider cameras as being part of that package, a monitoring of the property that would inherently reduce the inhabitant's privacy. But in our question sets, choices where high security was partnered with low invasiveness occurred, implying that these choices are unrealistic. However, this study was meant to understand the attributes that respondents valued for their older adult relative, rather than understanding how each individual technology or product increases or decreases the value of the attribute.

Additionally, due to the use of a survey panel, our sample was not representative of the larger population, leading to a sample population who are more educated, more wealthy, and less ethnically diverse compared to the general population. Additionally, the use of the survey panel meant that the survey was sent to members of the panel, 250 of whom completed the survey. It is impossible to know how these 250 respondents differed from respondents who partially completed the survey or who did not submit their survey back to Qualtrics. Due to concerns about the length of the survey, and response rates being low if the survey was too long, questions which would have given more nuanced information regarding the main findings were omitted.

## 5. Conclusion

The findings of this study illustrate that, compared to previously conducted research, relatives of older adults' value security, safety, moderate ability to communicate/socialize, and lower costs, while not valuing privacy. Results also indicate that younger adults may believe that their older relatives live in un-safe and un-secured homes, feelings which may not reflect the opinions and feelings of the older relative in question. With the population of older adults in the US continuing to grow, and our nation's strong desire for older adults to age in place, the need to balance safe and secure independent living while respecting the privacy of older adults will be an ever-growing challenge.

## Conclusion

### *Summary of Goals*

The proportions of older adults in the United States is continually growing. By 2050, nearly one in five Americans will be over the age of 65.[2] With this increase in the proportion of older adults living in the United States, the United States government expects the number of age-related health problems and unintentional falls to increase as well.[1] These age-related problems increase the risk of falls, which are associated with poorer quality of life, high levels of anxiety, and are costly to treat.[68] The cost of treating fall injuries was estimated to be around $29.4 billion in 2009, and the informal caregiving provided to older adults following a fall injury is estimated to be over $450 billion annually.[66,154] Because fall injuries affect so many older adults in the United States, research needs to be focused on reducing the number of fall injuries sustained by older adults, ultimately reducing the physical pain, increasing wellness, and decreasing healthcare costs for this population. This dissertation set out to accomplish 3 goals:

1. Examine risk factors that predict subsequent fall injury and death among older adult fallers reporting to the ED.
2. Understand the preferences of rural older adults towards various home modifications and smart home technologies, which may increase an older person's ability to age in place, to determine whether they perceive value or benefits in utilizing these technologies.
3. Examine the preferences that family members/caregivers of older adults have towards attributes related to the adoption of smart technologies and home modifications for older adult relatives aging in place.

Conducting research to answer these three goals enables (1) identification of various risk factors that increase the risk of suffering a fall injury, and building a profile of at-risk populations; (2) better understanding of what technologies and home modifications rural older adults are considering installing in their home for the purpose of aging in place; and (3) elucidation of how family members of older adults value attributes related to home modifications and smart home technologies.

### *Summary and Implications of the Research*

The results of the research conducted yielded several important findings. The first study was conducted in order to build a profile of older adults who are at greater risk of suffering subsequent fall injury and death following an initial fall injury. Using statewide emergency department record and linked death data, it was found that females, non-Hispanic Whites, and individuals with multiple comorbid medical conditions, prior ED utilization, prior diagnoses of substance use, and those living in lower-SES areas as being at higher risk of suffering subsequent fall injury and death. The results also indicate that 35% of fallers had a subsequent fall injury over the three year follow up period, and another 31% of fallers died following their initial fall injury. The identification of females, non-Hispanic Whites, individuals with multiple ED visits in the past year, and those with various comorbidities being at higher risk of suffering subsequent fall injury underscores the importance of providing these individuals with interventions in the

emergency department setting. With approximately one in three older adult fallers suffering from a subsequent fall or dying within three years of their initial fall, we can use this timeframe to implement potential interventions or programs aimed at reducing injury and death following the initial fall.

The second study focused on rural older adults because large populations of older adults live in rural areas, those living in rural areas face unique challenges, and because research on rural populations is scarce. Research indicates large numbers of retirees are choosing to move to rural areas in order to sustain more cost effective and independent lifestyles, turning many rural areas into retirement communities.[21] However, many rural areas have been designated as being medically underserved, with few rural communities having adequate levels of geriatric care or accommodations designed for older adults.[132] For older adults in rural areas, installing home modifications or the adopting of smart home technologies may be a viable safety strategy to reduce the risk of fall related injury. Results from the interviews conducted among rural older adults indicate that older adults living in rural environments are not opposed to adopting home modifications and technology if they feel there is a need. But that feeling of need, and the perceived usefulness of various smart home technologies, is negated by high levels of social and community cohesion, especially among residents of dedicated retirement communities; comparatively, those living on their own private properties perceived these technologies and home modification devices as being more useful, and ultimately more interested in investing in the technology. This study also identified barriers to adopting technologies among this population, including cost, ability to learn and memorize commands, desire for privacy, and a lack of information about available smart home technologies.

The third study examined the preferences of relatives of older adults towards home modifications and smart home technologies in the form of a discrete choice survey. Examining the preferences of this group was done because relatives of older adults provide several hundred billion dollars' worth of informal care given to older adults annually.[16] This impact on the families of these older adults may be lessened by the installation of home modifications and adoption of smart home technologies. The results from the discrete choice experiment found that relatives of older adults valued the attributes of security, safety, and the ability to communicate/socialize. Respondents of this survey also valued lower costs and were not concerned about invading the privacy of their older adult relatives. Additionally, the respondents reported feeling that their older relatives lived in unsafe and un-secured homes, feelings that may not reflect those of the older relative in question.

Notably, findings from the literature and the second study indicated that older adults are concerned with how the adoption of smart home technologies may compromise their privacy. Findings from the third research project found that younger relatives of older adults were not concerned about invading the privacy of their older relatives. Additionally, although the emergency department data indicating that females and Non-Hispanic Whites (a group which made up the majority of older adult relatives in the third study) were at increased risk of suffering from subsequent fall injury, respondents in the third study did not prefer packages with increased levels of security or safety. With

younger family members having some sort of say in the living arrangement of their older adult relatives, bridging these differences in values will become important to give older adults the best chance to age in place while respecting their privacy, and give their family members peace of mind.

*Section 3: Recommendations for future research*

This dissertation points to smart home technologies and home modifications as one possible avenue to help decrease fall injury and increase the ability of older adults to age in place safely. However, there are many questions which still need to be answered. Future research should aim to identify whether the adoption of home modifications and smart home technologies, among fallers who are treated in the emergency department setting, decreases rates of subsequent fall injury, or increases the length of time between initial and subsequent fall injuries. Identifying which products these older adults invest in would help researchers identify specific modifications and technologies to investigate and promote for more general adoption among older adults looking to age in place.

Regarding rural populations of older adults, future research should aim to address the barriers facing these residents as they consider their need for home modifications and technologies. In countries outside the US, government entities are responsible for subsidizing the cost of safety modifications to the home. If the installation of various home modifications and smart home technologies is found to be effective at reducing injury, it would be beneficial to propose government funding towards helping older adults afford them. Alternatively, if investing in these technologies and modifications is found to be cost effective for the individual, increased rates of adoption may increase regardless of potential government subsidization. Either way, helping provide evidence for or against the effectiveness of these developing technologies will help older adults and their families make informed decisions in how to best help them age in place.

With younger family members providing several hundred million dollars' worth of informal care for older relatives annually, considering their preferences towards home modifications and smart home technologies is also important. Family members are interested in products which increase the security, safety, and communication ability of their older relatives. Future research should determine what products are most desired among these family members, and how acceptable these products are among their older relatives. With privacy being a top concern for older adults, but not an important concern for their family members, it is important to find a way to find ways to increase security, safety, and communication without compromising the independence and privacy of older adults hoping to continue aging in place. Developing technologies to meet the expectations and goals of older adults and their family members would help increase the confidence and trust of potential buyers in the technologies and modifications ultimately created to support them as they age in place.

*Conclusion*

As the proportion of older adults in the United States continues to grow, finding ways to reduce fall injury will become important to decrease overall healthcare spending and increase the wellbeing of the older adult population. The research conducted in this

dissertation identifies at-risk populations, the average time between an index fall injury and subsequent fall and death, the preferences of rural older adults towards smart home technologies, and the perceptions of family members of older adults towards important attributes considered during the process of deciding whether to adopt technologies. Taken as a whole, this dissertation presents various avenues for future research aimed at reducing fall injury, and identifying ways to increase security, safety, and communication for older adults living in the community using technologies and home modifications.

While outside the scope of this dissertation, it is often the case that technologies are developed and sold to consumers before robust third-party testing of their efficacy can be conducted. This dissertation highlights the wealth of choice older adults and their families have in regards to smart home products, and how little peer-reviewed research has been conducted regarding their efficacy and how useful their intended user base (older adults) feels such technologies are. Collectively, consumers spent nearly $30 billion in 2014 on various smart home technologies marketed as increasing security, safety, and communication.[144] With companies continuing to invest heavily in their development, it is critical that we research the appropriateness of implementing, and the overall efficacy of, these technologies as part of a preventive strategy for decreasing the public health burden of fall injuries among older adults living in the United States.

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**Tables**

**Table 1.1:** Description of Unintentional Fall ICD-9-CM codes including Frequency among Index Fall Visits

| ICD-9-CM Code | Description | Frequency | % |
|---|---|---|---|
| E880 | Accidental fall on or from stairs or steps | 9,232 | 5.3 |
| E881 | Accidental fall on or from ladders or scaffolding | 2,225 | 1.3 |
| E882 | Accidental fall from or out of building or other structure | 157 | 0.1 |
| E883 | Accidental fall into hole or other opening in surface | 133 | 0.1 |
| E884 | Other accidental falls from one level to another | 16,984 | 9.7 |
| E885 | Accidental fall on same level from slipping tripping or stumbling | 72,453 | 41.6 |
| E886 | Fall on same level, pushing, or shoving, by or with other person | 284 | 0.2 |
| E887 | Fracture, cause unspecified | 1,941 | 1.1 |
| E888 | Other and unspecified fall | 70,897 | 40.7 |

**Table 1.2:** Ten most common external injury codes reported among fallers at index visit

| ICD-9-CM Code | Description | Frequency | % |
|---|---|---|---|
| E849 | Home accident | 111,673 | 64.1 |
| E000 | Work related accident | 49,131 | 28.2 |
| E001 | Activities involving walking | 3,373 | 1.9 |
| E029 | Other activity | 3,169 | 1.8 |
| E030 | Unspecified activity | 2,815 | 1.6 |
| E013 | Activities involving bathing and showering | 985 | 0.6 |
| E016 | Activities involving land maintenance, building, construction | 465 | 0.3 |
| E934 | Adverse effect of blood constituents | 286 | 0.2 |
| E019 | Activities involving animal care | 248 | 0.1 |
| E935 | Adverse effects of painkiller, antipyretics and antirheumatics | 217 | 0.1 |
| **Total** | | **172,362** | **98.99** |

**Table 1.3.** Demographic and clinical characteristics at index visit among patients aged ≥65 years presenting to California emergency departments or hospitals in 2010.

| | Other patients | | Fall patients | |
|---|---|---|---|---|
| | 934,595 | | 174,220 | |
| **Sex** | | | | |
| Male | 413,762 | 44.3% | 58,163 | 33.4% |
| Female | 520,829 | 55.7% | 116,057 | 66.6% |
| **Age group** | | | | |
| 65-69 | 235,863 | 25.2% | 26,313 | 15.1% |
| 70-74 | 194,448 | 20.8% | 25,800 | 14.8% |
| 75-79 | 175,757 | 18.8% | 29,459 | 16.9% |
| 80-84 | 154,681 | 16.6% | 35,104 | 20.2% |
| 85-89 | 112,094 | 12.0% | 34,022 | 19.5% |
| 90 or older | 61,752 | 6.6% | 23,522 | 13.5% |
| **Race/ethnicity** | | | | |
| White | 592,388 | 63.4% | 124,477 | 71.5% |
| Black | 63,629 | 6.8% | 7,008 | 4.0% |
| Hispanic | 160,385 | 17.2% | 25,313 | 14.5% |
| Asian/Pacific Islander | 89,075 | 9.5% | 12,995 | 7.5% |
| Other | 29,118 | 3.1% | 4,427 | 2.5% |
| **Charlson Comorbidity Index** | | | | |
| Score 0 | 370,510 | 39.6% | 91,059 | 52.3% |
| Score 1-2 | 191,180 | 20.5% | 31,813 | 18.3% |
| Score 3-4 | 36,920 | 4.0% | 4,970 | 2.9% |
| Score 5 or more | 335,985 | 36.0% | 46,378 | 26.6% |
| **Malnutrition diagnosis** | 47,226 | 5.1% | 5,796 | 3.3% |
| **Substance use disorder** | 19,501 | 2.1% | 5,175 | 3.00% |
| **Disposition** | | | | |
| Home | 789,821 | 86.0% | 131,649 | 76.4% |
| Skilled Nursing Care/LTC | 87,123 | 9.4% | 32,925 | 19.1% |
| Trans to another health institution | 29,246 | 3.2% | 6,392 | 3.7% |
| Other | 12,115 | 1.3% | 1,286 | 0.8% |
| **Past-year history of ED utilization** | | | | |
| Any visit | 335,133 | 35.9% | 62,686 | 36.0% |
| **Insurance status** | | | | |
| Self-pay | 10,731 | 1.2% | 1,764 | 1.0% |
| Medicare | 638,267 | 68.3% | 114,982 | 66.0% |
| Medi-Cal | 30,420 | 3.3% | 3,338 | 1.9% |
| Private | 248,742 | 26.6% | 52,561 | 30.2% |
| Other/unknown | 5,908 | 0.6% | 1,506 | 0.9% |

| | | | | |
|---|---|---|---|---|
| **Urbanicity** | | | | |
| Metropolitan | 862,614 | 92.3% | 160,585 | 92.2% |
| Micropolitan | 47,273 | 5.1% | 9,158 | 5.3% |
| Small Town/rural | 24,699 | 2.6% | 4,477 | 2.6% |
| **Zip code socioeconomic disadvantage** | | | | |
| First quartile (lowest disadvantage) | 251,385 | 26.9% | 50,724 | 29.1% |
| Second quartile | 236,350 | 25.3% | 46,407 | 26.6% |
| Third quartile | 230,327 | 24.7% | 41,859 | 24.0% |
| Fourth quartile (highest) | 216,420 | 23.2% | 35,212 | 20.2% |

[a]Patients who died at index visit are not included in other cumulative estimates.

**Table 1.4:** Risk factors for repeat fall following the index fall injury, among patients with an index fall in 2010.

| | Bivariate Analysis | | Multivariate Analysis | |
|---|---|---|---|---|
| | IRR | 95% CI | IRR | 95% CI |
| **Sex** | | | | |
| Male | 1.00 | | 1.00 | |
| Female | 1.05 | (1.03, 1.07) | 1.04 | (1.03, 1.06) |
| **Age group** | | | | |
| 65-69 | 1.00 | | 1.00 | |
| 70-74 | 1.14 | (1.10, 1.18) | 1.11 | (1.07, 1.15) |
| 75-79 | 1.44 | (1.39, 1.49) | 1.38 | (1.34, 1.43) |
| 80-84 | 1.78 | (1.72, 1.83) | 1.70 | (1.64, 1.75) |
| 85-89 | 2.11 | (2.05, 2.18) | 2.00 | (1.94, 2.07) |
| 90 or older | 2.34 | (2.26, 2.42) | 2.23 | (2.16, 2.31) |
| **Race** | | | | |
| White | 1.00 | | 1.00 | |
| Black | 0.76 | (0.73, 0.80) | 0.78 | (0.75, 0.82) |
| Hispanic | 0.83 | (0.81, 0.85) | 0.87 | (0.84, 0.89) |
| Asian/Pacific Islander | 0.69 | (0.66, 0.71) | 0.70 | (0.68, 0.73) |
| Other | 0.56 | (0.53, 0.60) | 0.64 | (0.60, 0.68) |
| **Charlson Comorbidity Index** | | | | |
| Score 0 | 1.00 | | 1.00 | |
| Score 1-2 | 1.13 | (1.10, 1.15) | 1.12 | (1.09, 1.14) |
| Score 3-4 | 1.26 | (1.19, 1.32) | 1.20 | (1.14, 1.27) |
| Score 5 or more | 1.27 | (1.24, 1.29) | 1.09 | (1.07, 1.12) |
| **Malnutrition diagnosis** | 0.99 | (0.94, 1.04) | 0.91 | (0.86, 0.96) |
| **Substance use disorder** | 1.12 | (1.07, 1.18) | 1.28 | (1.22, 1.34) |
| **Disposition** | | | | |
| Home | 1.00 | | 1.00 | |
| Skilled Nursing Care/LTC | 1.15 | (1.12, 1.17) | 0.94 | (0.92, 0.96) |
| Trans to another health institution | 1.78 | (1.71, 1.85) | 1.64 | (1.58, 1.71) |
| Other | 1.15 | (1.04, 1.28) | 1.16 | (1.05, 1.29) |
| **Past-year history of ED utilization** | | | | |
| Any visit | 1.51 | (1.48, 1.53) | 1.45 | (1.42, 1.47) |
| **Insurance status** | | | | |
| Self-pay | 1.00 | | 1.00 | |
| Medicare | 1.42 | (1.29, 1.56) | 1.11 | (1.01, 1.22) |
| Medi-Cal | 1.07 | (0.95, 1.21) | 1.06 | (0.95, 1.19) |

| | | | | |
|---|---|---|---|---|
| Private | 1.31 | (1.19, 1.45) | 1.11 | (1.01, 1.22) |
| Other/Unknown | 0.88 | (0.76, 1.01) | 0.87 | (0.75, 1.00) |
| **Urbanicity** | | | | |
| Metropolitan | 1.00 | | 1.00 | |
| Micropolitan | 1.13 | (1.09, 1.17) | 1.08 | (1.04, 1.12) |
| Small Town/rural | 1.05 | (1.00, 1.11) | 1.03 | (0.97, 1.08) |
| **Zip code socioeconomic disadvantage** | | | | |
| First quartile (lowest disadvantage) | 1.00 | | 1.00 | |
| Second quartile | 1.02 | (0.99, 1.04) | 1.01 | (0.98, 1.03) |
| Third quartile | 1.03 | (1.00, 1.05) | 1.04 | (1.01, 1.06) |
| Fourth quartile (highest) | 1.01 | (0.98, 1.04) | 1.06 | (1.04, 1.09) |

**Table 1.5:** Risk factors for death following the index fall injury

| | Bivariate Analysis | | Multivariate Analysis | |
|---|---|---|---|---|
| | IRR | 95% CI | IRR | 95% CI |
| **Sex** | | | | |
| Male | 1.00 | | 1.00 | |
| Female | 0.65 | (0.64, 0.67) | 0.64 | (0.63, 0.65) |
| **Age group** | | | | |
| 65-69 | 1.00 | | 1.00 | |
| 70-74 | 1.39 | (1.33, 1.46) | 1.31 | (1.25, 1.37) |
| 75-79 | 1.97 | (1.89, 2.06) | 1.74 | (1.67, 1.82) |
| 80-84 | 2.78 | (2.67, 2.89) | 2.37 | (2.27, 2.47) |
| 85-89 | 3.92 | (3.77, 4.08) | 3.21 | (3.09, 3.35) |
| 90 or older | 5.95 | (5.72, 6.20) | 4.87 | (4.67, 5.07) |
| **Race/ethnicity** | | | | |
| White | 1.00 | | 1.00 | |
| Black | 0.85 | (0.81, 0.89) | 0.92 | (0.88, 0.97) |
| Hispanic | 0.71 | (0.69, 0.73) | 0.81 | (0.79, 0.83) |
| Asian/Pacific Islander | 0.72 | (0.70, 0.75) | 0.74 | (0.71, 0.77) |
| Other | 0.62 | (0.58, 0.66) | 0.77 | (0.72, 0.82) |
| **Charlson Comorbidity Index** | | | | |
| Score 0 | 1.00 | | 1.00 | |
| Score 1-2 | 1.50 | (1.47, 1.54) | 1.41 | (1.37, 1.45) |
| Score 3-4 | 2.61 | (2.50, 2.74) | 2.09 | (2.00, 2.19) |
| Score 5 or more | 2.89 | (2.83, 2.95) | 1.88 | (1.84, 1.92) |
| **Malnutrition diagnosis** | 2.67 | (2.57, 2.77) | 1.55 | (1.49, 1.61) |
| **Substance use disorder** | 1.04 | (0.99, 1.10) | 1.02 | (0.96, 1.07) |
| **Disposition** | | | | |
| Home | 1.00 | | 1.00 | |
| Skilled Nursing Care/LTC | 2.16 | (2.12, 2.21) | 1.37 | (1.33, 1.40) |
| Trans to another health institution | 1.73 | (1.66, 1.80) | 1.31 | (1.25, 1.36) |
| Other | 1.85 | (1.69, 2.03) | 1.66 | (1.52, 1.82) |
| **Past-year history of ED utilization** | | | | |
| Any visit | 1.59 | (1.56, 1.62) | 1.44 | (1.42, 1.47) |
| **Insurance status** | | | | |
| Self-pay | 1.00 | | 1.00 | |
| Medicare | 2.01 | (1.79, 2.25) | 1.13 | (1.01, 1.27) |
| Medi-Cal | 1.35 | (1.18, 1.55) | 1.00 | (0.87, 1.14) |
| Private | 1.44 | (1.28, 1.61) | 1.12 | (1.00, 1.26) |

| | | | | |
|---|---|---|---|---|
| Other/Unknown | 0.98 | (0.82, 1.16) | 0.93 | (0.78, 1.10) |
| **Urbanicity** | | | | |
| Metropolitan | 1.00 | | 1.00 | |
| Micropolitan | 1.07 | (1.03, 1.11) | 1.05 | (1.01, 1.10) |
| Small Town/rural | 0.95 | (0.89, 1.00) | 0.99 | (0.93, 1.05) |
| **Zipcode socioeconomic disadvantage** | | | | |
| First quartile (lowest disadvantage) | 1.00 | | 1.00 | |
| Second quartile | 1.06 | (1.04, 1.09) | 1.06 | (1.03, 1.08) |
| Third quartile | 1.06 | (1.03, 1.08) | 1.11 | (1.08, 1.14) |
| Fourth quartile (highest) | 1.03 | (1.00, 1.06) | 1.14 | (1.11, 1.17) |

**Table 2.1:** Guiding questions

1. Have you ever had a fall related injury? If so, what happened?
2. Have you changed anything in your environment to prevent further injury? If so, what did you do?
3. Did your children ever approach you about preventing further injury? If so, what did they talk to you about?
4. Have you considered any home modifications or technologies to prevent injury? If so, have you installed any or made any changes?
5. What challenges, if any, do you feel are unique to older adults living in a rural environment?
6. Do you think there is anything I need to know to better understand your experience as an older adult in a rural area?

**Table 2.2:** Descriptive Characteristics of Older Adults

| | |
|---|---|
| N | 12 |
| **Age** | Range: 68-88 |
| **Sex** | |
| Female | 7 |
| Male | 5 |
| **Marital Status** | |
| Married | 5 |
| Divorced/widowed | 6 |
| Single/never married | 1 |
| **Number of children** | Range: 0-5 |
| **Type of Home** | |
| Home | 5 |
| Apartment | 2 |
| Mobile home | 5 |
| **Has long term care insurance** | |
| Yes | 2 |
| **Ever had a fall** | |
| Yes | 10 |

**Table 3.1:** Attribute and Attribute levels for labeled choice between home modification packages

| Attribute | Level | Description | Examples of technology or modification |
|---|---|---|---|
| **Security** | High | Completely safe exterior of the home, no risk of break in | Security doors, outside cameras, automatic lights, alarm system, in addition to a lock on exterior doors |
| | Medium | Increased security at the exterior of the home | Alarm system and automatic lights in addition to a lock on exterior doors |
| | Low | No extra security measures | Lock on exterior doors |
| **Safety** | High | Complete confidence that no home injuries or accidents will occur | Cameras inside the home, railings and grab bars in walkways and the bathroom (around the toilet and in the shower), automatic lights in rooms, and life-alert or other wearable device which can contact emergency services. |
| | Medium | Increased confidence that no home injuries or accidents will occur | Railings and grab bars in walkways and the bathroom (around the toilet and in the shower) and life-alert or other wearable device which can contact emergency services. |
| | Low | No increased confidence that home injuries or accidents would occur less often | Does not include any installations or additional technology which promotes safety |
| **Communication** | High | Complete confidence that they will be able to contact anyone when they need to | Tablet, reliable home wi-fi, cell phone, and a laptop/computer |
| | Medium | Increased confidence that they will be | Cell phone and a laptop/computer |

| | | | |
|---|---|---|---|
| | | able to contact anyone when they need to | |
| | Low | No increased confidence that they will be able to contact anyone when they need to | Does not include any installations or additional technology which promotes communication |
| **Invasiveness** | High | No privacy, ability to know what they are doing in their home at anytime | |
| | Medium | Moderate privacy, ability to know what they are doing in common spaces | |
| | Low | Complete privacy, no ability to know what they are doing inside their home | |
| **Cost** | $0 | | |
| | $1,000 | | |
| | $5,000 | | |
| | $10,000 | | |
| | $20,000 | | |
| | $50,000 | | |

**Table 3.2:** Demographics of Survey Respondents (n=250)

| | N | % / SD |
|---|---|---|
| **Age** | 60.7 | 13.8 |
| **Sex** | | |
| Female | 152 | 60.8 |
| Male | 98 | 39.2 |
| **Race** | | |
| White | 195 | 78.0 |
| Black | 15 | 6.0 |
| Hispanic/Latino | 14 | 5.6 |
| Asian | 22 | 8.8 |
| Other | 4 | 1.6 |
| **Education** | | |
| Less than High School | 0 | 0.0 |
| High School | 23 | 9.2 |
| Some College | 83 | 33.2 |
| College or More | 144 | 57.6 |
| **Income** | | |
| Less than 10K | 8 | 3.2 |
| 10K - 40K | 44 | 17.6 |
| 40K - 70K | 60 | 24.0 |
| 70K-100K | 48 | 19.2 |
| 100K - 150K | 46 | 18.4 |
| More than 150K | 44 | 17.6 |
| **Marital Status** | | |
| Single/Never Married | 39 | 15.6 |
| Married | 145 | 58.0 |
| Divorced, Widowed | 66 | 26.4 |

| **Table 3.3:** Demographics of Older Adult Relative | | |
|---|---|---|
| | N | %/ SD |
| **Age** | 81.5 | 8.3 |
| **Sex** | | |
| Female | 190 | 76.0 |
| Male | 60 | 24.0 |
| **Relative Selected** | | |
| Grandparent | 42 | 16.8 |
| Parent | 123 | 49.2 |
| Aunt/Uncle | 29 | 11.6 |
| Sibling | 56 | 22.4 |
| **Knowledge of:** | | |
| **Computer** | | |
| No proficiency | 61 | 24.4 |
| A little proficiency | 48 | 19.2 |
| Moderate proficiency | 66 | 26.4 |
| High proficiency | 75 | 30.0 |
| **Smartphone** | | |
| No proficiency | 57 | 22.8 |
| A little proficiency | 51 | 20.4 |
| Moderate proficiency | 71 | 28.4 |
| High proficiency | 71 | 28.4 |
| **Tablet** | | |
| No proficiency | 96 | 38.4 |
| A little proficiency | 39 | 15.6 |
| Moderate proficiency | 56 | 22.4 |
| High proficiency | 59 | 23.6 |
| **Internet** | | |
| No proficiency | 59 | 23.6 |
| A little proficiency | 58 | 23.2 |
| Moderate proficiency | 50 | 20.0 |
| High proficiency | 83 | 33.2 |
| **Need Mobility Device** | | |
| **Walker** | | |
| No Need | 185 | 74.0 |
| Need- Uses daily | 34 | 13.6 |
| Need- Uses occasionally | 31 | 12.4 |
| **Wheelchair** | | |
| No Need | 223 | 89.2 |
| Need- Uses daily | 6 | 2.4 |

| | | |
|---|---|---|
| Need- Uses occasionally | 21 | 8.4 |

**Table 3.4:** Frequency of the number of respondents who reported being confident that they could complete tasks required to care for their older adult relative

| **Assisting Task** | **N** | **%** |
|---|---|---|
| Eating, Bathing, Toileting, Dressing | 208 | 83.2 |
| Coordinate medications and medical care | 122 | 48.8 |
| Manage difficult behaviors | 184 | 73.6 |
| Manage emotional needs | 180 | 72.0 |
| Help them communicate | 208 | 83.2 |
| Mange finances | 197 | 78.8 |
| Manage transportation | 211 | 84.4 |
| Find paid help | 180 | 72.0 |
| Find Activities | 192 | 76.8 |
| Have enough time to provide care | 174 | 69.6 |
| Have enough physical space | 165 | 66.0 |

**Table 3.5:** Attributes Valued by Respondents using a Conditional (Fixed-Effect) Logistic Regression Model:

| | Beta coef | (SE) | P-Value | Beta coef | (SE) | P-Value | WTP |
|---|---|---|---|---|---|---|---|
| **Security** | | | | | | | |
| Low | 0.00 | | | 0.00 | | | |
| Medium | 0.23 | 0.05 | <0.001 | 0.19 | 0.05 | <0.001 | $4,597.22 |
| High | 0.23 | 0.05 | <0.001 | 0.20 | 0.05 | <0.001 | $4,750.45 |
| **Safety** | | | | | | | |
| Low | 0.00 | | | 0.00 | | | |
| Medium | 0.14 | 0.05 | 0.007 | 0.15 | 0.05 | 0.003 | $3,585.26 |
| High | 0.26 | 0.05 | <0.001 | 0.24 | 0.05 | <0.001 | $5,757.18 |
| **Communication** | | | | | | | |
| Low | 0.00 | | | 0.00 | | | |
| Medium | 0.24 | 0.06 | <0.001 | 0.22 | 0.06 | <0.001 | $5,294.17 |
| High | -0.01 | 0.05 | 0.817 | -0.03 | 0.05 | 0.511 | -$810.55 |
| **Invasive** | | | | | | | |
| Low | 0.00 | | | 0.00 | | | |
| Medium | 0.13 | 0.05 | 0.01 | 0.15 | 0.05 | 0.004 | $3,544.25 |
| High | 0.41 | 0.05 | <0.001 | 0.42 | 0.05 | <0.001 | $10,248.10 |
| **Cost** | | | | | | | |
| 0 | 0.00 | | | | | | |
| 1,000 | -0.20 | 0.07 | 0.004 | | | | |
| 5,000 | -0.52 | 0.07 | <0.001 | | | | |
| 10,000 | -0.86 | 0.07 | <0.001 | | | | |
| 20,000 | -1.38 | 0.07 | <0.001 | | | | |
| 50,000 | -1.99 | 0.09 | <0.001 | | | | |
| **Linearized Cost** | | | | 0.00 | 0.00 | <0.001 | |

**Table 3.6:** Attributes Valued by Respondents using a Conditional (Fixed-Effect) Logistic Regression Model: Stratified by Gender of Older Adult

| | | | **Females** | |
|---|---|---|---|---|
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | | | |
| Medium | 0.24 | 0.06 | 0.771 | $5,979.88 |
| High | 0.21 | 0.06 | 0.154 | $5,338.67 |
| **Safety** | | | | |
| Low | 0.00 | | | |
| Medium | 0.19 | 0.06 | 0.972 | $4,843.69 |
| High | 0.30 | 0.06 | 0.562 | $7,368.18 |
| **Communication** | | | | |
| Low | 0.00 | | | |
| Medium | 0.22 | 0.06 | 0.068 | $5,434.94 |
| High | -0.02 | 0.06 | 0.463 | -$491.37 |
| **Invasive** | | | | |
| Low | 0.00 | | | |
| Medium | 0.16 | 0.06 | 0.431 | $4,080.39 |
| High | 0.41 | 0.06 | <0.001 | $10,126.98 |
| **Linearized Cost** | -4.01E-05 | 1.87E-06 | <0.001 | |
| | | | **Males** | |
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | 0.00 | 0.00 | |
| Medium | 0.03 | 0.03 | 0.03 | $5,979.88 |
| High | 0.15 | 0.15 | 0.15 | $5,338.67 |
| **Safety** | | | | |
| Low | 0.00 | 0.00 | 0.00 | |
| Medium | 0.00 | 0.00 | 0.00 | $4,843.69 |
| High | 0.06 | 0.06 | 0.06 | $7,368.18 |
| **Communication** | | | | |
| Low | 0.00 | 0.00 | 0.00 | |
| Medium | 0.21 | 0.21 | 0.21 | $5,434.94 |
| High | -0.08 | -0.08 | -0.08 | -$491.37 |
| **Invasive** | | | | |
| Low | 0.00 | 0.00 | 0.00 | |
| Medium | 0.08 | 0.08 | 0.08 | $4,080.39 |
| High | 0.48 | 0.48 | 0.48 | $10,126.98 |
| **Linearized Cost** | -4.48E-05 | -4.48E-05 | -4.48E-05 | |

**Table 3.7:** Conditional (fixed effect) Model Stratified by Older Adult's relationship with Respondent

| | | | **Grandparent** | |
|---|---|---|---|---|
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | | | |
| Medium | 0.27 | 0.12 | 0.031 | $9,722.70 |
| High | 0.23 | 0.12 | 0.06 | $8,519.07 |
| **Safety** | | | | |
| Low | 0.00 | | | |
| Medium | -0.05 | 0.12 | 0.647 | -$2,001.29 |
| High | -0.31 | 0.13 | 0.017 | -$11,215.56 |
| **Communication** | | | | |
| Low | 0.00 | | | |
| Medium | -0.11 | 0.13 | 0.392 | -$3,940.70 |
| High | -0.26 | 0.12 | 0.03 | -$9,661.26 |
| **Invasive** | | | | |
| Low | 0.00 | | | |
| Medium | 0.03 | 0.12 | 0.838 | $924.48 |
| High | 0.14 | 0.12 | 0.253 | $4,987.66 |
| **Linearized Cost** | -2.73E-05 | 3.46E-06 | <0.001 | |
| | | | **Parent** | |
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | | | |
| Medium | 0.18 | 0.07 | 0.015 | $4,307.88 |
| High | 0.24 | 0.07 | 0.001 | $5,749.05 |
| **Safety** | | | | |
| Low | 0.00 | | | |
| Medium | 0.13 | 0.07 | 0.062 | $3,196.96 |
| High | 0.34 | 0.08 | <0.001 | $8,167.16 |
| **Communication** | | | | |
| Low | 0.00 | | | |
| Medium | 0.29 | 0.08 | <0.001 | $6,961.37 |
| High | 0.09 | 0.07 | 0.203 | $2,234.23 |
| **Invasive** | | | | |
| Low | 0.00 | | | |
| Medium | 0.22 | 0.07 | 0.003 | $5,300.87 |
| High | 0.56 | 0.07 | <0.001 | $13,379.62 |
| **Linearized Cost** | -4.17E-05 | 2.36E-06 | 2.36E-06 | |

| | Aunt/Uncle | | | |
|---|---|---|---|---|
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | | | |
| Medium | 0.06 | 0.17 | 0.742 | $730.53 |
| High | 0.02 | 0.17 | 0.892 | $296.07 |
| **Safety** | | | | |
| Low | 0.00 | | | |
| Medium | 0.11 | 0.16 | 0.503 | $1,422.08 |
| High | 0.48 | 0.17 | 0.005 | $6,249.91 |
| **Communication** | | | | |
| Low | 0.00 | | | |
| Medium | 0.03 | 0.17 | 0.875 | $354.14 |
| High | -0.18 | 0.17 | 0.28 | -$2,335.38 |
| **Invasive** | | | | |
| Low | 0.00 | | | |
| Medium | 0.25 | 0.17 | 0.143 | $3,219.03 |
| High | 0.31 | 0.16 | 0.057 | $4,013.65 |
| **Linearized Cost** | -7.74E-05 | 7.52E-06 | <0.001 | |
| | **Sibling** | | | |
| | Beta coef | (SE) | P-Value | WTP |
| **Security** | | | | |
| Low | 0.00 | 0.00 | 0.00 | $6,291.54 |
| Medium | 0.26 | 0.26 | 0.26 | $4,957.28 |
| High | 0.21 | 0.21 | 0.21 | |
| **Safety** | | | | |
| Low | 0.00 | 0.00 | 0.00 | $9,468.35 |
| Medium | 0.39 | 0.39 | 0.39 | $8,657.53 |
| High | 0.36 | 0.36 | 0.36 | |
| **Communication** | | | | |
| Low | 0.00 | 0.00 | 0.00 | $12,236.61 |
| Medium | 0.51 | 0.51 | 0.51 | -$100.36 |
| High | 0.00 | 0.00 | 0.00 | |
| **Invasive** | | | | |
| Low | 0.00 | 0.00 | 0.00 | $2,951.65 |
| Medium | 0.12 | 0.12 | 0.12 | $10,612.45 |
| High | 0.44 | 0.44 | 0.44 | $6,291.54 |
| **Linearized Cost** | -4.16E-05 | 3.43E-06 | <0.001 | |

## Figures

**Figure 1.1:** Cumulative incidence of falls and death over study period

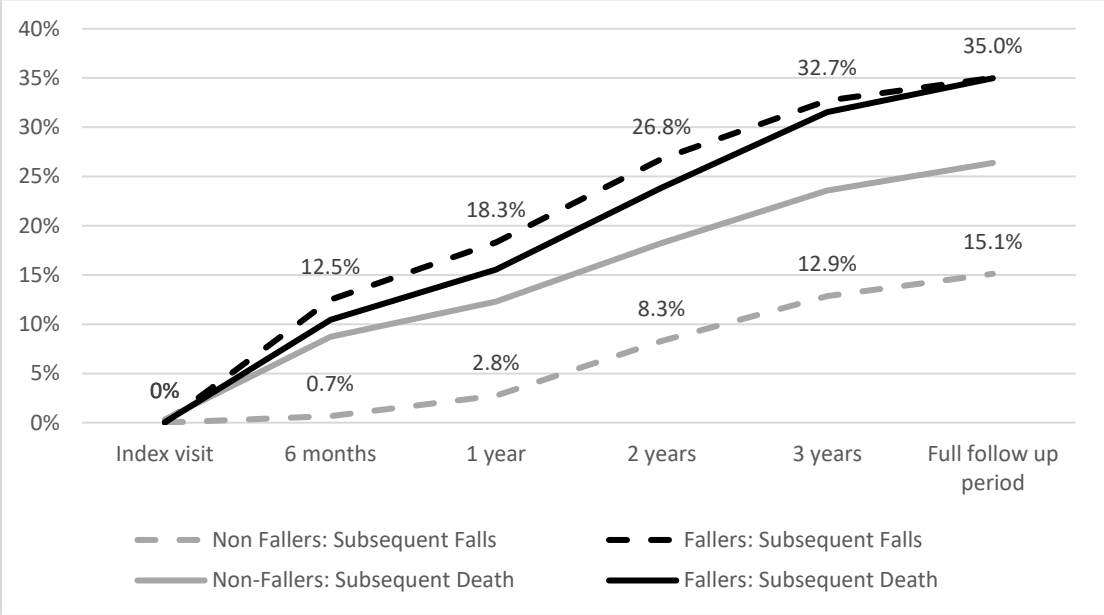

**Figure 3.1:** Example of a Discrete Choice Experiment Choice Set

If these were your only options, which choice would you prefer?

| (8 of 16) | Choice 1 | Choice 2 | Choice 3 |
|---|---|---|---|
| security | completely safe exterior of the home, no risk of break in | increased security at the exterior of the home | I would prefer they move in with me |
| safety | no increased confidence that home injuries or accidents would occur less often | increased confidence that no home injuries or accidents will occur | |
| communication | increased confidence that your Older Family Member will be able to contact anyone when they need to | complete confidence that your Older Family Member will be able to contact anyone when they need to | |
| invasiveness | your Older Family Members has no privacy, you, or another person, are able to know exactly what they are doing in their home at any given time | your Older Family Members has no privacy, you, or another person, are able to know exactly what they are doing in their home at any given time | |
| cost | $1,000 | $20,000 | $50,000 |

I would prefer Choice 1
I would prefer Choice 2
I would prefer Choice 3

**Figure 3.2:** Comparing the homes of respondents and their older adult relative on security, safety, and communication/socialization.